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INTERNAL DOSE FOLLOWING A LARGE-SCALE NUCLEAR WAR

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ABSTRACT

The relationship between external and internal doses from exposure to nuclear radiation has become increasingly better defined during the past several years. During atmospheric testing of nuclear explosives in the 1950's and early 1960's, little was known of the relative magnitude of the internal dose to people from ingestion of foods contaminated by radioactivity. During the 1970's, models were developed to estimate the contribution of internal dose to the total dose. These early models were designed primarily for application to long-term releases, such as from nuclear power plants. In the 1980's advanced dynamic models for terrestrial food paths appeared. These are capable, with the proper input, of reconstructing internal doses to people who were affected by radiation from past atmospheric nuclear tests. The same models are ideally suited for estimating the internal doses to people that might result from multiple explosions, over a relatively short time, produced by a large-scale nuclear war.

In this study, we use the PATHWAY model, in conjunction with a reasonable hypothetical nuclear attack on the U.S., to arrive at calculations of internal and external dose estimates that are based on valid model results. Our own estimates are presented with calculational aids (at every step) that enable readers to use their own nuclear war scenarios, fallout

patterns, assumptions about the climatic changes brought on by large fires following a nuclear attack, the viability of the transportation system for food delivery, the quality and quantity of water and foods available locally, the required caloric intakes of the survivors, and several other factors.

Using our own input, we have calculated the internal and external doses for 10 locations within the U.S. These studies have variable external doses, shelter factors, availability of foods from nearby government distribution agencies, other foods available within walking or bicycling distances, and other variables. Our calculations show that the ratios of internal to external dose vary from less than zero to 107 percent. Seven of the case studies have ratios less than 10 percent. The higher ratios result from the effects of a large shelter factor (reducing the external dose) and consumption of contaminated foraged food for long periods (increasing the internal dose).

We conclude that the average American family that survived a large-scale nuclear war, using their own home or workplace as a refuge, would receive a total internal dose from ingestion that is from one to 10 percent of the total external dose. Those who stayed where shelter protection factors and foraged food consumption were large could receive internal doses from 11 percent to more than 100% of the total external dose

INTRODUCTION

Following single or multiple nuclear explosions, persons downwind of the resultant radioactive fallout can be exposed to both external and internal doses from the radiation generated, primarily, by the fission part of the weapon. While fallout is occurring, the external dose is caused partly by radioactive particles passing overhead ("cloud shine") and the immersion dose received as the particles move past the person. However, the major contributor to the external dose, particularly in the long term, is from the deposition of radioactive particles on the surface; this is because the potential exposure time is much longer.

Internal dose is caused by inhalation and ingestion of radioactivity. The inhalation dose occurs when falling or resuspended particles are breathed into the lungs, where they can be transferred to other organs. For Pu-239, inhalation is virtually the only pathway for internal dose. Dose from ingestion occurs after the radioactive particles have deposited on the ground or on a water surface.

Dose from consumption of contaminated water is a straightforward pathway. For edible crops, the path is more complex and involves a multitude of factors, such as the season of the year, the structure of the plants and their growth rate, the rate at which specific nuclides pass through the leaves or roots, the effects of resuspension and rainsplash, the type of soil, weathering of nuclides (from plants to soil), percolation and leaching of the radioactivity in the soil, nuclide uptake by roots, and when the crops are harvested.

Doses via the livestock pathway depend on such variables as the type of animal, the percentages of fresh and stored feeds, the quantity of nuclides in these feeds, the amount of soil ingested by the animal and the ingestion, absorption, and excretion rate of nuclides.

Since the 1950's, extensive studies have been made on the magnitude of the external dose to humans from fallout following the explosion of nuclear weapons, including simulated attacks on the United States. Some recent examples of such research appear in the TTAPS [Tu83], OTA [OTA79], and SCOPE [Pi86] studies. Quantitative estimates of external doses to humans requires a fallout pattern, a population distribution, and the extent of sheltering and evacuation of people during the first few months after a nuclear war.

The literature on internal dose estimation is far less abundant than that for external dose. Past studies usually have been confined to atmospheric tests. Whicker and Kirchner [Wi87] refer to studies indicating that ". . . .doses to most organs from external radiation from fallout on the ground tend to be of the same order to roughly tenfold higher than internal doses via ingestion." Rotblat [Ro84] estimates that internal dose is (a) roughly 20% of the external dose from local fallout, (b) about equivalent for intermediate fallout, and (c) somewhat greater than external dose from long-term fallout.

Part of the reason that more research has not been devoted to internal dose estimates that might result from a nuclear war is that, in addition to fallout, population dynamics, and sheltering, we have to consider the survivors' diets. This requires assumptions about the quantities of food and uncontaminated water that families have on hand at the onset of the war. Then, when stored supplies are exhausted, estimates must be made of (a) the external dose families would receive while foraging for food and water from government distribution centers, or supermarkets (these two sources, if available, would most likely be uncontaminated), farmers, fields, and (b) how much internal dose they would receive from consuming these foraged foods and water. In areas that initially received heavy fallout, foods grown in the contaminated soil, could give substantial doses for months or years later. Also, if climatic perturbations (caused by smoke and soot from fires started by nuclear bursts) occurred, the amount of foodstuffs and their internal dose potential would be affected.

We present a "users manual" approach in this report to enable readers to estimate internal doses based on their own assumptions about fallout patterns, shelter factors, the amount of water and the types and quantities of stored food, and the foods and water available from local sources. We also present our own range of internal dose estimates and give calculations of the internal and external doses, following a hypothetical nuclear war, for a fictitious family in St. Louis, Missouri. Appendices contain detailed internal and external dose estimates for 9 other locations within the U.S., blank copies of the dose calculation sheets (for an alternative scenario), and a discussion of milk pooling.

In the next sections, we will identify:

- The radionuclides that would contribute the most to internal dose,
- The most significant food pathways,
- The organs affected most by these nuclides, and
- The relative effects on internal dose of climatic perturbations caused by nuclear war.

SELECTION OF PRINCIPAL RADIONUCLIDES

A nuclear explosion creates over 200 radionuclides which have a wide ranges of yield, half–life, and physical, chemical, and biological properties. Only a small number of these are significant sources for internal dose to humans via ingestion.

The most important radionuclides for internal dose were selected from dose reconstructions of 24 persons who lived near, but in various directions from, the Nevada Test Site (NTS) during periods of atmospheric nuclear weapons testing in the 1950's (Ng88). Each had consumed foods that were exposed to fallout from 2 to 8 (median of 5) atmospheric tests. Their organ and total body doses were estimated from (1) exposure rates measured in their communities after each atmospheric nuclear test, (2) surface deposition as calculated by Hicks from measured external exposure rates [Hi84], and (3) the integrated intakes of radionuclides (estimated by the PATHWAY model [Wh87]), and (4) committed dose factors. Because in the 1950's it was believed that the internal doses produced by atmospheric tests were small, no mitigating actions were taken and the residents continued to consume the same foods as at other times.

As part of the assessment of these 24 people, the doses to 11 internal organs, including the total body, were estimated for 20 radionuclides. For this report, the radionuclides contributing to the total body doses were given the most attention. Initially, the 10 nuclides that gave the largest total body internal dose were selected. These 10 accounted for about 90% of the total internal dose from all 20 nuclides. Some of these most significant nuclides did not appear within the 10 highest for all of the people.

When the number of most significant nuclides was reduced to four, the percentage of total dose averaged seventy-three percent and all four of the selected nuclides appeared at or near the top of the list for all 24 subjects.

These nuclides, in relative order of importance, are Cs-137, Sr-90 (together accounting for about 50% of total body internal dose), I-131, and Sr-89. The range in percentages of total dose varied from 54 to 83% of the 20 nuclide total, representing, principally, variations in diet. A graph of these percentages for all 24 people, identified as persons A to X, is shown in Figure 1.

INTERNAL DOSE PATHWAYS

The two primary pathways for internal dose are inhalation and ingestion. It has been determined that, except for dose from I-131 to the thyroid, inhalation is a minor contributor to dose when compared to ingestion [Wh87]. In large part, this is because inhalation is only significant during cloud passage or when local fallout is occurring. Following that, resuspension of surface deposition, which occurs at unpredictable times during moderate to strong surface winds, is the only natural mechanism capable of producing inhalation doses.

External exposure from I-131 (or internal exposure to other organs, except the thyroid) is much smaller than the total body dose from ingestion. Therefore, ingestion of contaminated water and food, which could occur for years after a single deposition event, is the only internal pathway considered in this report. The principal ingestion pathways are given in a later section.

CALCULATION OF INGESTION DOSE CONVERSION FACTORS

We define an ingestion dose conversion factor (DCF) as the dose commitment to an organ of an individual of a specific age, via a particular pathway, that would result from a unit deposition of radioactivity. DCF units are given in Sv per MBq / m^2 (or mrem per uCi / m^2). Multiplication of a DCF by a surface deposition value provides a dose estimate to an individual to the organ for which the DCF applies. Implicit in the DCF estimate are assumptions about the types, quantities, and contamination of food that would be consumed by humans and the dose per unit intake of the radionuclides.

Several models were considered as candidates for calculating DCFs. These included HERMES [Fl71], and later versions of HERMES,such as FOOD [Ba76]. The major problem of using these models for internal dose calculations from a nuclear war is that they were designed for estimating routine annual doses from nuclear power facilities and are not applicable to relatively short, multiple releases. Two models that do not have this restriction are PATHWAY [Wh87) and RADFOOD [Ko86].

PATHWAY was selected as the model of choice, not only because it is a dynamic model for terrestrial food paths, but also because it is applicable to deposition over a period of hours to days, involving one burst or multi-

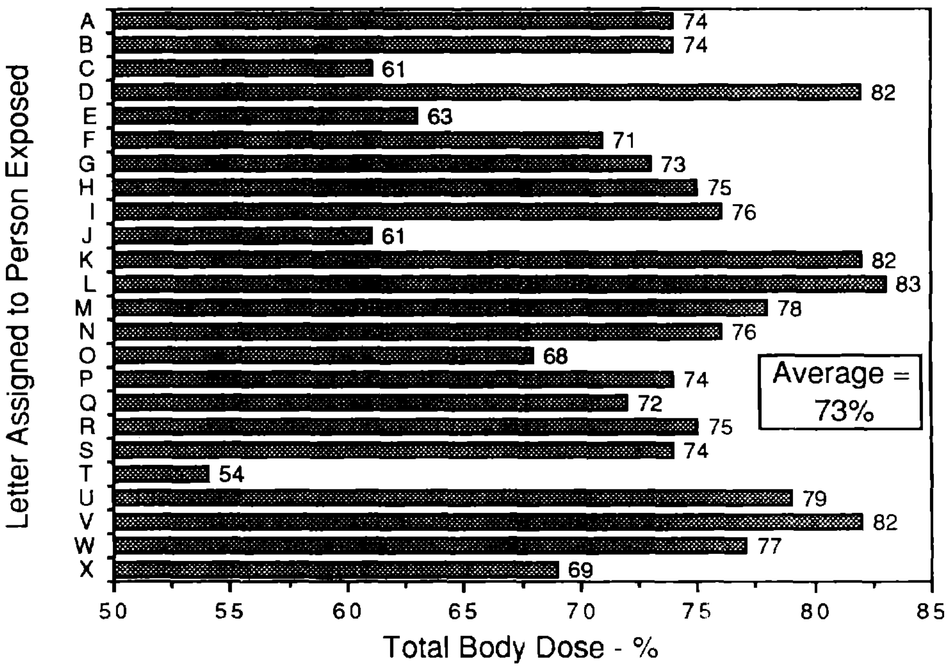


Figure 1. Percent of reconstructed Total Body ingestion doses from sum of Sr-89, Sr-90, I-131, and Cs-137 for 24 offsite residents exposed to fallout from nuclear explosions at the Nevada Test Site during the 1950's.

ple bursts from nuclear explosions. It also estimates intake from a fallout field resulting from multiple sources. Depending upon the radionuclide, the dose estimates for a short release differ from those for continuous releases. Koch and Tadmor [Ko86] state that, "...the steady-state (equilibrium) approach [used by annual dose models] is not suitable for the description of acute radioactivity releases, following nuclear power plant accidents or nuclear explosions. These are characterized by transient peaks of radioactivity along the food chain and thus changes occurring with time are of particular importance."

PATHWAY is a computerized foodchain transport model that calculates the time-integrated human ingestion intake after a single deposition from the atmosphere to the surface. Concentrations of radionuclides in soil, vegetation, animal tissues, and animal products are estimated by solving a system of linear-coupled differential equations. The model accounts for interception by plant surfaces, weathering, absorption, plant growth, uptake, harvest, senescence, soil resuspension, percolation, leaching, tillage, radioactive decay, livestock ingestion and excretion and other processes. Additional features of PATHWAY are human dietary intake, seasonal changes in the biomass of vegetation, animal diets, and plowing and harvest times.

The PATHWAY model is site specific to a region, but can use agricultural data bases for any climatic regime. The PATHWAY authors used agricultural data for the area within several hundred kilometers of the Nevada Test Site. The crops are assumed to be irrigated and livestock are assumed to graze on irrigated pastures or from stored feed. Stored feeds in the western United States are usually protected by physical barriers and are relatively uncontaminated by fallout. In addition, the percentage of locally grown food types is an integral part of the model as applied to the western U.S.

Our application of PATHWAY assumes that, following a nuclear war, families initially would use pre-war food sources stored at home. In nearly all cases, this food would have, at most, negligible levels of radiation. We also assume that, when stored food has been consumed, survivors leave their refuge and forage for food that would be available locally (at farms, fields, or government distribution centers). Most of this food, except that obtained from the government, would be contaminated by fallout to some extent.

The specific foods that are modeled in PATHWAY include milk, beef, poultry, leafy and non-leafy vegetables, and grain. Root uptake by crops is not considered in evaluating ingestion dose because it "...contributes little to the human dose under the circumstances to which PATHWAY applies ..." [Wh87].

The food dietary intake model that is used in the published version of PATHWAY [Wh87] does not include sufficient data for either lamb or hog meat. For these foods we suggest that the DCFs for beef be used. Aquatic biota are also not included. This is because fish are not available in abundance as a major food source. Rupp [Ru80] estimates that the average daily adult intake of saltwater fish in the U.S. is 12% of daily beef consumption; for freshwater fish, the ratio drops to less than 2%. Also, freshwater fish and saltwater fish within the continental shelf would be heavily contaminated by fallout, which would circulate within the relatively shallow body of water and eventually sink to the bottom, to be ingested by bottom–feeders.

Dose from ingestion of Pu-239 has not been included because of its small surface concentration and minimal biological transport. Its dose via ingestion is negligible compared to the nuclides that we have selected [Wh87].

Using the PATHWAY model, the DCFs in Sv per Bq/m^2 (and rem per Ci/m^2) are calculated from:

$$DCF = TIC * DT * DF \tag{1}$$

where *TIC* is the time-integrated concentration in food per unit fallout deposition (Bq day / kg per Bq / m^2) from the PATHWAY model, *DT* is the average U.S. dietary consumption (kg / day), from Rupp [Ru80], *DF* is the dose factor (Sv / Bq) obtained from Y. Ng [Ng88].

TIC depends on the ingestion path, nuclide, time of year, and ingestion pathway; *DT* is a function of age and sex and represents U.S. average food consumption for 1965, the latest year for which national data are available; *DF* (from Ng88) depends on nuclide, age, and body organ. Figure 2 graphically illustrates the functional dependence of factors that contribute to *TIC*, *DT*, *DF*, and *DCF*.

For the DCFs developed during this study, we have assumed a nuclear attack in July so as to assess the internal dose at the season when fresh food is most readily available and the climatic impact is believed to be the most severe on agriculture.[1] Two age categories have been chosen: adult (18 years or older) and child (1 to 11 years). For adults, we have selected both sexes; PATHWAY assumes that the adult female's daily food intake is about 80% of adult males. On average, most children under 12 consume about the same amount of food, regardless of sex. It is possible, with different dose factors, to calculate DCFs for infants (less than 1 year) and teenagers (12 to 17 years). However, in the interest of simplicity, we assume that infants consume the same types and amounts as children; teenagers are assumed to consume the same quantities as adults.

As mentioned earlier, four radionuclides were selected. These account for 73% of the reconstructed total body dose: Sr-89, Sr-90, I-131, and Cs-137. The DCFs for no or slight climatic effects are presented in Table 1 in

[1] In the absence of food supplies from the government, an attack during the winter could result in mass starvation since fresh foods would not be available for most of the U.S.

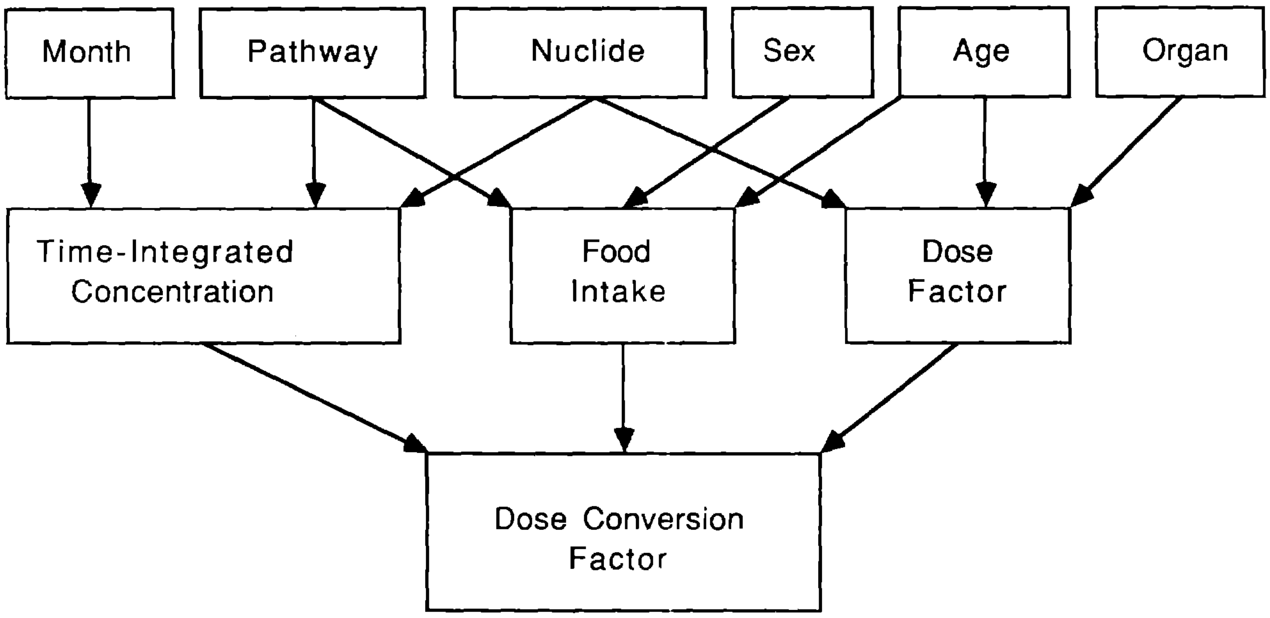


Figure 2. A flow chart illustrating the relationship between variables that contribute to a dose conversion factor in the PATHWAY model

Table 1. Dose conversion factors (DCFs) for principal radionuclides producing ingestion doses in humans following a major nuclear war with no or slight degrees of climatic perturbations due to large fires. DCF units are Sv per Mega Bq/m^2 and (in parentheses) Rem per μCi/m^2.

Nuclide	Pathway	Organ	Age*	DCF for Climatic Changes that Are: None or Slight
^{89}Sr	Milk	Total Body	A	2.16×10^{-5}
				(8.02×10^{-5})
			C	1.91×10^{-4}
				(7.07×10^{-4})
		Bone Surface	A	1.48×10^{-4}
				(5.49×10^{-4})
			C	1.00×10^{-3}
				(3.70×10^{-3})
		Red Bone Marrow	A	1.02×10^{-4}
				(3.77×10^{-4})
			C	6.87×10^{-4}
				(2.54×10^{-3})
^{89}Sr	Beef	Total Body	A	3.39×10^{-6}
				(1.26×10^{-5})
			C	6.38×10^{-6}
				(2.36×10^{-5})
		Bone Surface	A	2.32×10^{-5}
				(8.60×10^{-5})
			C	3.33×10^{-5}
				(1.23×10^{-4})
		Red Bone Marrow	A	1.59×10^{-5}
				(5.90×10^{-5})
			C	2.28×10^{-5}
				(8.44×10^{-5})
^{89}Sr	Poultry	Total Body	A	2.21×10^{-8}
				(8.20×10^{-8})
			C	6.26×10^{-8}
				(2.32×10^{-7})

* Age: A = Adult Male > 18 yrs. C = Child 1 to 11 yrs.

		Bone Surface	A	1.52×10^{-7} (5.62×10^{-7})
			C	3.42×10^{-7} (1.27×10^{-6})
		Red Bone Marrow	A	1.04×10^{-7} (3.86×10^{-7})
			C	2.33×10^{-7} (8.63×10^{-7})
^{89}Sr	Leafy Vegetable	Total Body	A	2.10×10^{-5} (7.78×10^{-5})
			C	3.58×10^{-5} (1.33×10^{-4})
		Bone Surface	A	1.44×10^{-4} (5.33×10^{-4})
			C	1.87×10^{-4} (6.93×10^{-4})
		Red Bone Marrow	A	9.89×10^{-5} (3.66×10^{-4})
			C	1.28×10^{-4} (4.74×10^{-4})
^{89}Sr	Non-Leafy Vegetable	Total Body	A	1.05×10^{-5} (3.88×10^{-5})
			C	3.94×10^{-5} (1.46×10^{-4})
		Bone Surface	A	7.17×10^{-5} (2.66×10^{-4})
			C	2.05×10^{-4} (7.59×10^{-4})
		Red Bone Marrow	A	4.93×10^{-5} (1.82×10^{-4})
			C	1.41×10^{-4} (5.22×10^{-4})
^{90}Sr	Milk	Total Body	A	1.82×10^{-3} (6.74×10^{-3})
			C	7.23×10^{-3} (2.68×10^{-2})

		Bone Surface	A	7.92×10^{-3} (2.93×10^{-2})
			C	3.15×10^{-2} (1.17×10^{-1})
		Red Bone Marrow	A	5.74×10^{-3} (2.13×10^{-2})
			C	2.28×10^{-2} (8.44×10^{-2})
^{90}Sr	Beef	Total Body	A	6.05×10^{-4} (2.24×10^{-3})
			C	5.11×10^{-4} (1.89×10^{-3})
		Bone Surface	A	2.63×10^{-3} (9.76×10^{-3})
			C	2.22×10^{-3} (8.15×10^{-3})
		Red Bone Marrow	A	1.91×10^{-3} (7.07×10^{-3})
			C	1.61×10^{-3} (5.96×10^{-3})
^{90}Sr	Poultry	Total Body	A	2.64×10^{-6} (9.77×10^{-6})
			C	3.49×10^{-6} (1.29×10^{-5})
		Bone Surface	A	1.15×10^{-5} (4.25×10^{-5})
			C	1.52×10^{-5} (5.63×10^{-5})
		Red Bone Marrow	A	8.32×10^{-6} (3.08×10^{-5})
			C	1.10×10^{-5} (4.07×10^{-5})
^{90}Sr	Leafy Vegetable	Total Body	A	1.54×10^{-3} (5.70×10^{-3})
			C	1.18×10^{-3} (4.37×10^{-3})

		Bone Surface	A	6.70×10^{-3} (2.48×10^{-2})
			C	5.12×10^{-3} (1.90×10^{-2})
		Red Bone Marrow	A	4.85×10^{-3} (1.80×10^{-2})
			C	3.71×10^{-3} (1.37×10^{-2})
^{90}Sr	Non-Leafy Vegetable	Total Body	A	8.64×10^{-4} (3.20×10^{-3})
			C	1.45×10^{-3} (5.37×10^{-3})
		Bone Surface	A	3.76×10^{-3} (1.39×10^{-2})
			C	6.32×10^{-3} (2.34×10^{-2})
		Red Bone Marrow	A	2.73×10^{-3} (1.01×10^{-2})
			C	4.59×10^{-3} (1.70×10^{-2})
^{90}Sr	Grain	Total Body	A	4.09×10^{-4} (1.51×10^{-3})
			C	7.01×10^{-4} (2.59×10^{-3})
		Bone Surface	A	1.78×10^{-3} (6.59×10^{-3})
			C	3.05×10^{-3} (1.13×10^{-2})
		Red Bone Marrow	A	1.29×10^{-3} (4.78×10^{-3})
			C	2.21×10^{-3} (8.18×10^{-3})
^{131}I	Milk	Total Body	A	1.69×10^{-5} (6.25×10^{-5})
			C	3.00×10^{-4} (1.11×10^{-3})

		Thyroid	A	2.42×10^{-2} (8.96×10^{-2})
			C	4.30×10^{-1} (1.59×10^{0})
^{131}I	Beef	Total Body	A	7.09×10^{-7} (2.63×10^{-6})
			C	2.67×10^{-6} (9.89×10^{-6})
		Thyroid	A	1.02×10^{-3} (3.77×10^{-3})
			C	1.81×10^{-2} (6.70×10^{-2})
^{131}I	Poultry	Total Body	A	2.86×10^{-9} (1.08×10^{-8})
			C	1.69×10^{-8} (6.26×10^{-8})
		Thyroid	A	4.11×10^{-6} (1.52×10^{-5})
			C	2.43×10^{-5} (9.00×10^{-5})
^{131}I	Leafy Vegetable	Total Body	A	3.04×10^{-6} (1.13×10^{-5})
			C	1.04×10^{-5} (3.85×10^{-5})
		Thyroid	A	4.36×10^{-3} (1.62×10^{-2})
			C	1.49×10^{-2} (5.52×10^{-2})
^{131}I	Non-Leafy Vegetable	Total Body	A	7.53×10^{-7} (2.79×10^{-6})
			C	5.66×10^{-6} (2.10×10^{-5})
		Thyroid	A	1.08×10^{-3} (4.00×10^{-3})
			C	8.12×10^{-3} (3.01×10^{-2})

^{137}Cs	Milk	Total Body	A	3.45×10^{-3} (1.28×10^{-2})
			C	6.39×10^{-3} (2.37×10^{-2})
^{137}Cs	Beef	Total Body	A	4.63×10^{-3} (1.72×10^{-2})
			C	1.82×10^{-3} (6.74×10^{-3})
^{137}Cs	Poultry	Total Body	A	2.31×10^{-4} (8.57×10^{-4})
			C	1.42×10^{-4} (5.26×10^{-4})
^{137}Cs	Leafy Vegetable	Total Body	A	6.08×10^{-4} (2.25×10^{-3})
			C	2.16×10^{-4} (8.00×10^{-4})
^{137}Cs	Non-Leafy Vegetable	Total Body	A	3.64×10^{-5} (1.35×10^{-4})
			C	3.09×10^{-5} (1.14×10^{-4})
^{137}Cs	Grain	Total Body	A	3.72×10^{-4} (1.38×10^{-3})
			C	2.97×10^{-4} (1.10×10^{-3})

Sv per Bq/m^2 (and, in rem per Ci/m^2, in parentheses) for the four nuclides, two age groups, and various food pathways.

CLIMATE CHANGES FROM A NUCLEAR WAR

Recently, a number of researchers using global climate computer models have shown that the injection into the atmosphere of large amounts of smoke and soot produced by fires generated by a hypothetical major nuclear war could produce significant changes in the earth's climate [Gh87;Ma86; Pi86;Th85;Tu83]. Despite many improvements in the modeling over the past 3 to 4 years, there remains considerable uncertainty in the climate projections, primarily because of the large uncertainties in the characteristics of the smoke injections assumed by the climate modelers [NRC85; Pe86]. Changes in climate are a subject of some dispute that has even extended to the arithmetic sign of surface temperature changes.

In this report, we attempt to quantify internal radiation dose in a climate perturbed by a nuclear war. We treat 4 categories of climate perturbation, viz., none or slight change, moderate, severe, and very severe. Table 1 shows the DCFs for no or slight climatic changes; if the perturbation is extremely severe in a region, all livestock and cultivated plants are presumed to be dead, making the DCF values meaningless. Using this approach, our analysis can be applied to a changing spectrum of calculated climate responses as the models and the input parameters continue to evolve.

To obtain quantitative estimates of the effects of the projected perturbed climate on internal dose calculations, we utilize the recent climate projections of Ghan, et al. [Gh87], who report on detailed calculations involving a July war. Ghan, et al., used the most recent version of the Livermore-modified Oregon State University (OSU) general circulation model (GCM). Smoke advection is treated by a Lagrangian technique, using the GRANTOUR model developed by Walton [Wa87]. The extent of the climatic perturbations obtained in the Ghan, et al., study are typical of those obtained by others in recent studies.

GRANTOUR is a three-dimensional transport and diffusion model driven by meteorological input generated by the OSU GCM [Sc80]. Particulates are advected by wind fields, locally diffused horizontally and vertically, moved vertically by convective fluxes and the re-evaporation of precipitation, and removed by precipitation scavenging and dry deposition. Unit mixing ratios are carried by Lagrangian parcels that move with the prescribed winds. We assume that the smoke particles appear in two size ranges, (1) greater than and (2) less than or equal to one micrometer in diameter. The larger particles are scavenged by precipitation with greater efficiency than the smaller ones. Thus, the climatic response depends on the assumed division of mass between the two size ranges. Coagulation from small to large particles is treated

The most relevant potential effects on climate are changes in surface air temperature, precipitation, and insolation. Each of these can potentially have a major impact on internal radiation doses from ingested food.

Figure 3a illustrates the temperature change during the first 10 days after a nuclear war in July. For these model calculations there are no areas of the U.S. where the temperature is reduced to below freezing, although there are some areas where the temperature is near freezing. By comparison, calculations by Malone [Ma86] for days 5 to 10 show most of the interior regions of the U.S. with temperature decreases more than 15 deg. C, and a few small regions of sub-freezing temperatures. Figure 3b depicts our calculations for percentage changes in precipitation for the initial 10 day time period. Figure 3c shows the percent changes in insolation at the surface for the same time period.

EFFECTS OF A PERTURBED CLIMATE ON INTERNAL DOSES

Following a nuclear war, it is expected that the smoke and soot from large fires would produce a perturbed atmosphere, causing reductions in surface temperature, precipitation, and insolation,[Gh87; Ma86; Pi86; Th85; Tu83]. In turn, the internal dose received by the surviving population would be somewhat larger than the internal dose in the absence of the climate perturbations.

For each food pathway, Table 2 lists our conception of the effects of reduced temperature, precipitation, and insolation on animal forage and cultivated crops. These provide a qualitative basis for adjusting the normal dose conversion factors for the effects of an atmosphere perturbed by smoke and soot, as shown in the last column. These are unsupported factors developed by the authors. They may be used as guides, if desired. Material presented later in this report enables readers to estimate internal doses using their own factors.

The column labelled "Other Effects" indicates that food consumption would be reduced following a nuclear war. This assumption is made because, today, most food is transported by truck, aircraft, or rail. A nuclear war would, most likely, disrupt large segments of the transportation industry, leading to food shortages, even with a reduction in the population due to prompt effects and local fallout.

The average American adult consumes between 2000 to 2500 kilocalories per day. With an adequate supply of water, it is known that initially healthy humans can live for up to 30 days without solid food, before irreversible health effects are encountered. This information comes from observations of people who have fasted for political or religious reasons and from persons who have been stranded with water, but with little or no food. About 1000 calories are required to keep adults and teenagers reasonably healthy, although at this intake level nearly all would lose weight.

a. Temperature departure from normal (deg. C)

b. Precipitation departure from normal (percent)

c. Insolation departure from normal (percent)

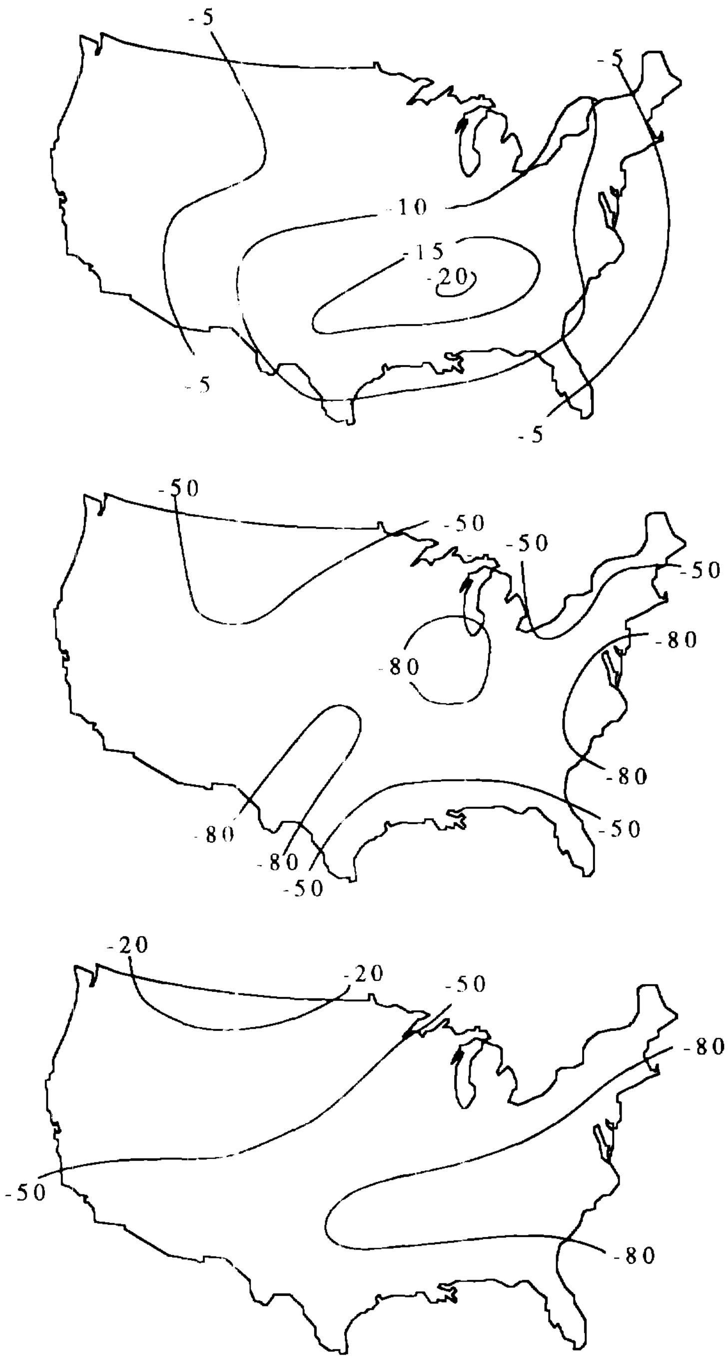


Figure 3. Climatic changes expected from large fires following a nuclear war in July. The three charts, based on work of Ghan and Walton, are applicable to the first week following the war.

Table 2. Climatic Perturbation Effects on Internal Doses from Ingestion.

Food Pathway	Reduced Temperature	Reduced Insolation	Reduced Precipitation	Other Effects	Multiplicative Factors for Climate Effects that are: Moderate	Severe
Milk and Meat (cows and steer on pasture).	Shorter, more sparse, slower growing grass: cow eats more soil.	Same as temperature effect.	Longer fallout retention on blades, less weathering, less growth.	Less consumption, less pooling (through cooperatives) of milk.	1.5	2.5
					(Cattle normally eat grass to a few cm. With retarded growth, would eat to 1 cm or less.)	
Milk and Meat(cows and steer on covered stored feed.)	Little effect if no grazing.	Little effect if no grazing.	Little effect if no grazing.	Less consumption. If stored feed unavailable, livestock would be on pasture	1.1	1.1
					(Stored feed is typically not airtight. A fraction of the fallout could cause slight contamination.)	
Lamb meat (lambs on pasture).	Same as cows and steer on pasture.	Same as at left.	Same as at left.	Consumption less.	1.3	2.0
					(Lambs usually eat grass to a shorter length than cattle. With retarded growth, would eat only slightly lower.)	
Hog meat. (Hogs generally eat corn and other grains.	Same as cows and steer on pasture or on stored feed	Same as at left.	Same as at left.	Consumption less. If dry feed unavailable would graze outside.	1.1	1.1
					On stored feed.	
					1.5	2.5
					In open field.	
Poultry. (Generally eat dry feed - corn and other grains).	Same as hog meat.	Same as hog meat.	Same as hog meat.	Consumption less. After a nuclear war, more poultry would likely eat outside.	1.1	1.1
					On stored feed.	
					1.5	2.5
					In open field.	
Leafy and non-leafy vegetables.	Slower growth, leading to higher fallout concentration.	Same as at left.	Fallout stays longer on leaves. Less weathering and growth	Consumption less. Possibly less water for proper washing.	1.5	2.5
					(Includes climatic effect, plus 0.5 from less effective washing.)	
Grain	Same as above.	Same as at left.	Same as above.	Consumption less.	1.5	2.5
					Smaller plant area, leading to less fallout retention.	
Aquatic Food.	Large effect on fish within the Continental Shelf and in lakes and streams. Small effect on seafish beyond the Continental Shelf.					

Following a nuclear war, we expect that the caloric intake would be less than under normal conditions. However, because of the stress expected in a post-war environment, it is reasonable to assume that survivors would wish to consume more than a starvation diet. In America, most families would probably have at least a 1 to 2 week supply of uncontaminated canned and other stored foods. For these reasons, we assume that the daily human caloric intake would average about 75 percent of normal, or about 1700 kilocalories per day for an adult or teenage male, 1400 kilocalories for an adult or teenage female, and 1000 kilocalories for a male or female child. Hence, the ratio of post-war to pre-war food energy intake, assumed to be about 0.75, will be used as a multiplicative factor in estimating food consumption rates following a nuclear war. Undoubtedly, not only the quantity, but also the mix of foods would be altered. The types of foods available to survivors would be strongly dependent on regional supplies. Most survivors would consume more of specific types of food, depending upon what is locally available Our "user's manual" approach allows the readers to use any post-war diet that they feel is appropriate.

There is currently a supply of several years of stored grain in the U.S. and nearly as much stored cheese [Gr86]. This food could be distributed to storage centers near those communities considered to be potential targets prior to a nuclear war, or distributed after a war (provided transportation to distribute and the equipment necessary to prepare grains for human consumption is available). Those who survived the prompt effects of the war and had access to several months supply of stored food would experience a very small internal dose due to ingestion. After that, the internal dose from fresh foods would come principally from Sr-90 and Cs-137.

The dose from consumption of fresh foods in the second year following a nuclear war would be considerably less than the first year[2] because of radioactive decay, runoff, percolation, and deep plowing of the soil. Furthermore, the transportation system should be restored sufficiently within three to six months to enable foodstuffs to be delivered from farms in areas that experienced relatively small radiation levels following the nuclear war.

DOSE CONVERSION FACTORS FOR A PERTURBED CLIMATE

All DCFs are for food that is produced locally and, unless stated otherwise, are for livestock and crops that remain unsheltered until consumption by humans.

Specification of criteria for determining climate perturbation factors for moderate and severe climatic changes are open to question since there are no measured data on climatic alterations following a nuclear war. Current

[2] We assume that climatic perturbations would be negligible in the second year; however, calculations have not been performed yet to verify this.

computer models offer a wide range of potential impacts. Perturbation values could range from slightly above normal to extremely large factors for the most severe climate changes. In order to estimate these factors, without adding several more climatic severity sub–classes, we have developed the relative factors in the last column of Table 2 to estimate the perturbation factors for moderate and severe climatic effects.

Table 1 presents the DCF values for normal or slight perturbation effects, obtained by solving Equation 1. These DCFs were calculated using the PATHWAY model with an average U.S. diet, as estimated by Rupp [Ru80]. In our internal dose calculations, we have used the dietary intake (instead of the Rupp diet) from local sources for several regions of the U.S. These estimates are based on U.S Department of Agriculture databases [DA87] of crops and livestock, by counties in the U.S. We have calculated the time-integrated doses for 10 locations with varying diets and fallout severity scattered over the U.S. The input and results for one location are given at the end of the text. Summary sheets for 9 other locations are presented in Appendix B.

FALLOUT PATTERN FOR A NUCLEAR ATTACK IN SUMMER

Since the purpose of this research is to compare external and internal doses from a nuclear war, this section discusses the selection of deposition patterns for the four radionuclides selected earlier. As a starting point, we have used the 48-hour integrated gross fission product external dose values of Harvey, et al. [Ha87] for a countervalue-counterforce attack on the continental U.S. in summer.

Using a credible target list, based on the best available knowledge of the Soviet's nuclear arsenal, Harvey et al. postulated a counterforce-countervalue attack of about 3000 Mton, using about 4000 weapons. Some 1900 Mton are assumed to be surface bursts. The study assumed that all weapons would be directed at military bases, military industrial facilities, and the politico-economic base of the U.S. No weapons would be aimed specifically at urban centers. However, because many targets are in or near cities, collateral effects on civilian populations would be unavoidable.

The attack day meteorology was selected from one of the more frequent atmospheric flow patterns as established by a 5-year typing scheme of daily 500 millibar (about 5.5 km) upper air charts [Ha87] for the contiguous U.S.

If sheltering or evacuation is not considered, the scenario results in a prediction of 98 million deaths due to prompt effects and an additional 10 to 13 million fallout fatalities. If none of the population were evacuated, but most were sheltered, the number of deaths from fallout drops to 0.7 million. The sheltering protection factors (PF) used were taken from Lee [Le76]. PF values ranged from 3 to 5 for single-story, woodframe houses, from 5 to 10 for multi-story residences, 20 to 60 for basements in structures of a single-story to a few stories, and 1000 or higher for deep basements of large buildings, subway stations, and tunnels located in metropolitan areas.

Those fatalities caused by blast, thermal, or prompt nuclear radiation were counted only once (unlike some earlier nuclear war studies). Studies based on analyses of the blast and thermal effects of the nuclear weapons exploded over Hiroshima and Nagasaki and nuclear weapons testing at the Nevada Test Site in the 1950's have shown that thermal effects extend farther from ground zero than blast effects [Po86]. The thermal conflagration model used in the Harvey study assumes: (a) a 100% fatality rate within a thermal fluence of 20 calories/cm^2 or greater, (b) a 70% fatality rate for fluences between 10 and 20 calories/cm^2, and (c) no fatalities from thermal fluences less than 10 calories/cm^2.

The model used to predict the fallout for our scenario was KDFOC2 [Ha79], which closely replicates many of the measured fallout patterns from atmospheric tests conducted at the Nevada Test Site. This model conserves radioactivity, uses observed vertical wind profiles, and emulates the geometry of a stabilized nuclear cloud. KDFOC2 operates by tracking, in space and time, a large number of vertically-stacked "altitude" disks. Each of these disks is segmented into many "particle-size" disks. All of the disks fall toward the surface under the influence of gravity, winds, and diffusion. For our nuclear war scenario, the model follows nearly 20 million disks.

The scenario used in calculating the fallout pattern assumed nuclear strikes against missile silos, military bases for surface forces, military airbases, military industrial facilities, submarine bases, nuclear weapons production facilities, and the politico-industrial base (including ports, petroleum refineries, electric power generating plants, and selected political targets of the United States). It was assumed that 75% of all military and 80% of all politico-economic targets were destroyed to an extent that they were rendered useless for several months or longer.

All the weapons were assumed to be of the fission-fusion-fission type with fission fractions of 50%. The population database was taken from the 1980 census [BC80] and was divided into two parts: urban and suburban-rural. The fallout pattern for the selected summer day is shown in Figure 4. The contours, varying from 1 to 10 Sv (100 to 1000 rem), are for an unsheltered population and represent integrated external gamma doses from time of arrival to 48 hours. The targeting scenario assumed airbursts on many targets that have been treated as surface bursts in some past fallout patterns. This is why in Figure 4 most of the western U.S. is not covered by cigar–shaped fallout patterns over most of the major population centers.

To obtain internal doses for the four selected radionuclides, it is necessary to have an estimate of their surface concentrations (in MBq/m^2). For this purpose, we have used the integrated dose contours of Figure 4 to

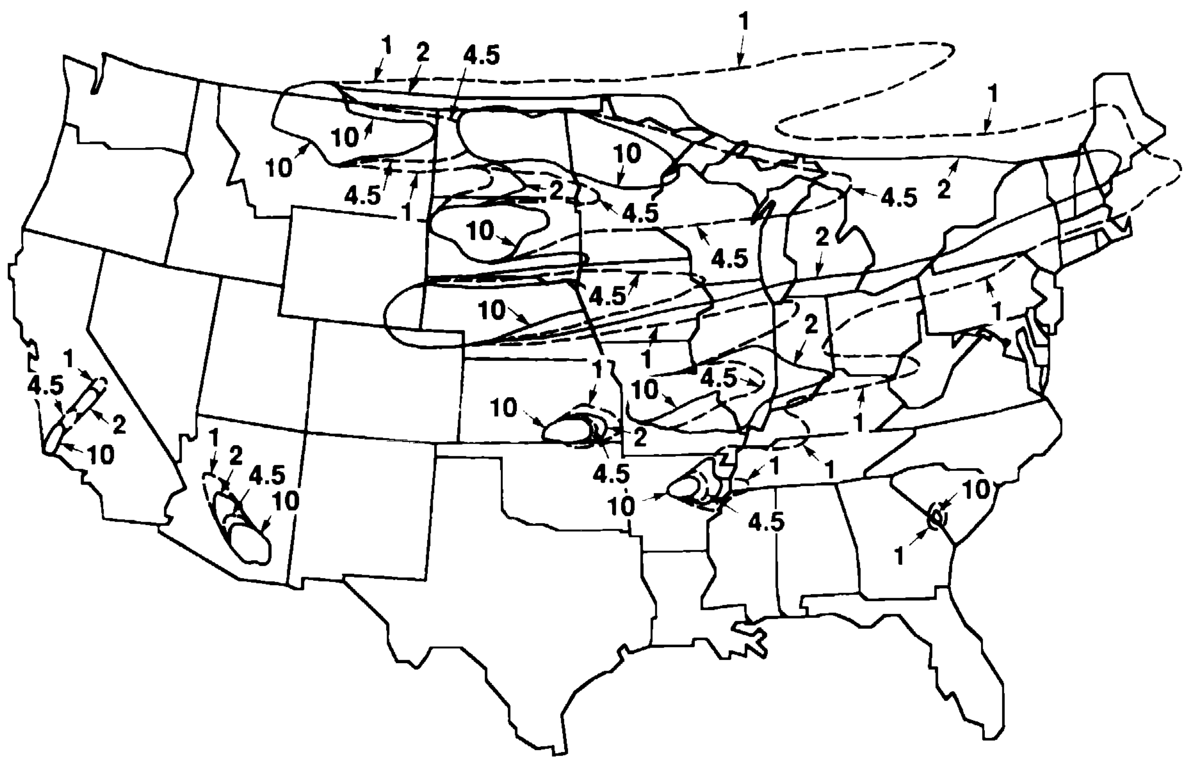


Figure 4: Fallout Pattern for a counterforce-countervalue attack on the U.S. in Summer. Contours are in sieverts.

develop a procedure that approximates nuclide areal densities to within about 50 percent.

The gross fission product contours are not convertible to exact nuclide areal densities because each fallout disk for this calculation was time-integrated from its time of arrival (TOA) to 48 hours; then all disks were summed. We assumed unfractionated fission products that followed the $t^{-1.2}$ time decay law.

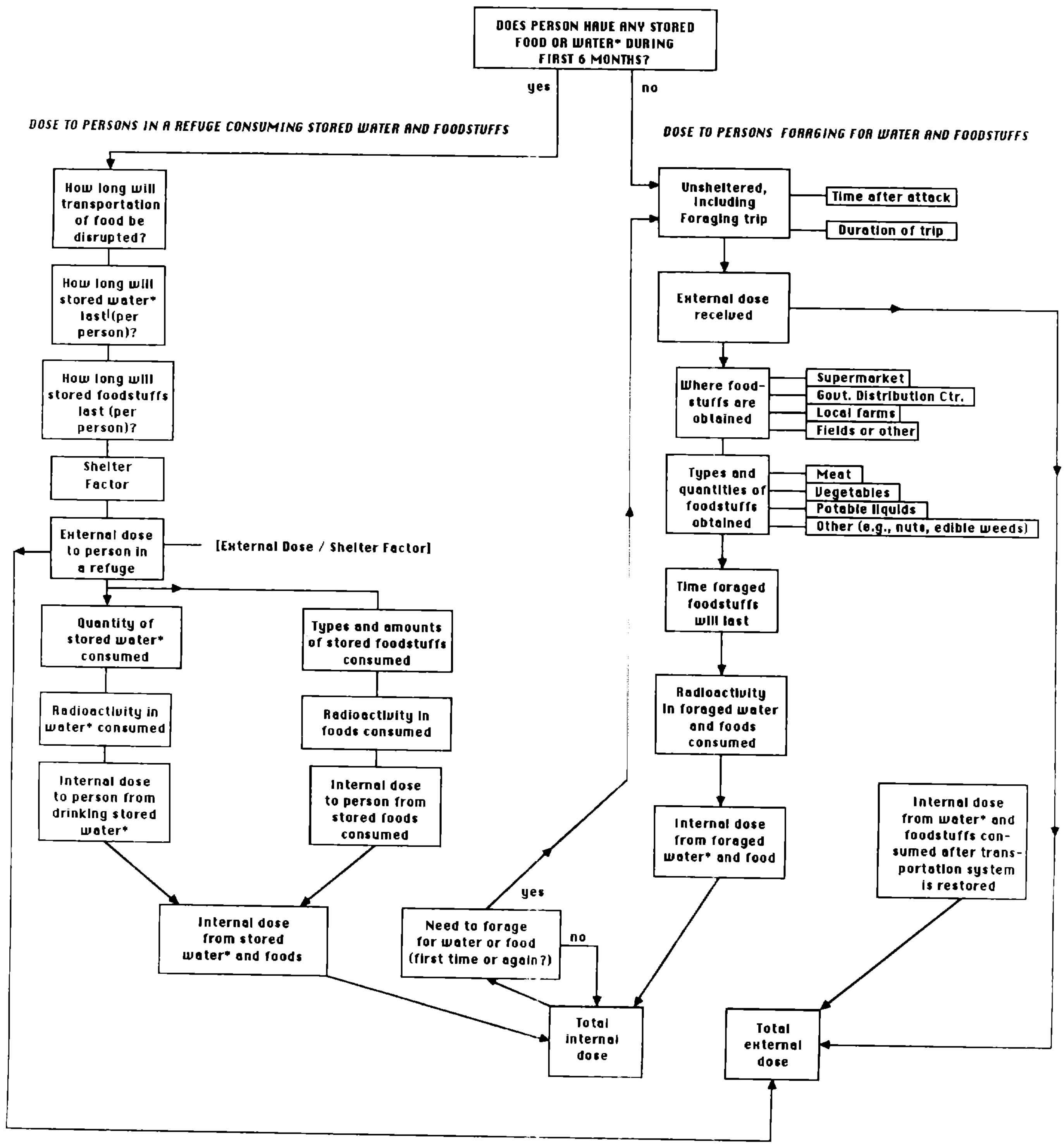
The KDFOC2 model rigorously conserves radioactivity; hence, the amount of a nuclide reaching a point could be exactly accounted for if the initial fraction of debris had been saved. Since this was not done, we instead specify a location-dependent "weighted" TOA for the areas of interest. Because of its central value, we assumed an overall TOA of ten hours. This approximates, within a factor of two, the dose on disks that arrive from 3 to 21 hours. Using this TOA and the chain yield of each nuclide from unmoderated neutron-induced fissions of U-235 [Cr77], factors were produced that approximately convert the gross fission product doses to surface depositions. These factors for the selected nuclides are shown in Table 3.

Table 3. Conversion factor of a 1 Sv time-integrated external dose (from H+10 to H+ 48) to a surface deposition (in MBq/m^2 per Sv) for the four significant radionuclides. U-235 fission is assumed.

Nuclide	Factor (MBq/m^2 per Sv)
Sr-89	18.
Sr-90	0.11
I-131	66.
Cs-137	0.12

INTERNAL DOSE ESTIMATION

Figure 5 is a flowchart presentation of the steps needed to calculate internal dose following a nuclear war. The left side of the figure is used to estimate how long stored water and food would last and what internal dose would be received from stored supplies. The right side shows the steps to calculate the internal dose from consumption of foraged water and food. Factors included in this assessment are how long the transport of food and water would be disrupted, how long stored and foraged water and food would last, the shelter factor of the refuge, the radioactivity in stored and foraged water and food, and the total external and internal doses to an individual. In general, the Work Sheet and the supplementary sheets follow the flowchart presentation. A set of these sheets have been filled in with our own default values. Most of these default values are given in Table 4. Internal dose calculations for 9 other locations are shown as summary



* Includes water and other potable liquids

"Refuge" means anything with a shelter factor greater than 1.0.
It can be anything from a tent in a field to a multi-story building in a large city.

Fig. 5. Flow chart illustrating the parameters used to calculate internal and external doses following a large-scale nuclear war.

sheets in Appendix B. Appendix C provides a blank Work Sheet and ancillary sheets which readers may use to prepare their own estimates of external and internal doses, using their own input values.

Table 4. Default values for Work Sheet variables used in estimating internal dose from a nuclear war.

Item No.	Description	Default value
3	Food transport Disrupted	1-3 months
5a	Drinking water	1 liter per person/day
5b	Washing and cooking water	0.5 liters per person/day
7a	Min. energy value of food	1700 kcal/day (male adult)
11a	Shelter Factors[3]	Single-story house: 2 to 5 Multistory apt.bldg: 5 to 10 Basement of multi-story apt.building: 20-60 Sub-basement of large urban bldg:100-1000

DESCRIPTION OF WORK SHEET AND AUXILIARY AIDS

The calculation of internal dose is accomplished by making entries into a series of forms which we call Sheets. The main form is the Work Sheet. This calls on other sheets, tables, and figures at various places. These ancillary aids include dose conversion factors (DCF) (Table 1), factors for enhancing the DCFs because of climatic changes due to smoke and soot (Table 2), energy values in kilojoules (kJ) and kilocalories (kcal) for many types of food, based on [De75] (Sheet A), decay factors from an initial time to a final time for gross fission products (Table 5), Sr-89 (Table 6), and I-131 (Table 7). The last three tables are used to determine radionuclide decay while in a refuge and while outside foraging for water and food (if these tables are not sufficiently accurate, the user should use the relevant equations at the bottom of Tables 5, 6, and 7).

Other aids used with the Work Sheet are U.S. maps of external dose following a 3000 Mton nuclear war (Figure 4) and deposition on the surface of Sr-89 (Figure 6), Sr-90 (Figure 7), I-131 (Figure 8), and Cs-137 (Figure 9). The deposition maps were generated from Figure 4, using the methodology described to prepare Table 3.

Finally, the other sheets that are used with the Work Sheet are Sheet B which with Sheet A is used to determine the energy value for each type (and the total) of stored or foraged food. Sheet C is used to estimate the internal dose from consuming foraged water (and stored water if it is contaminated by fallout). Sheet E provides estimates of internal dose from consuming foraged foods and is used in conjunction with Sheet A and Sheet D which give energy values for each type (and the total) for foraged foods.

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[3] Based on reference Ha77.

Time (after start of nuclear war) that external dose begins (days)

	1	2	3	4	5	7	10	15	20	30	40	50	75	100	150
100															0.1
75														0.1	0.2
50													0.1	0.2	0.3
40												0.1	0.2	0.2	0.3
30											0.1	0.2	0.3	0.3	0.4
20										0.1	0.2	0.3	0.4	0.5	0.6
15									01.	0.2	0.3	0.4	0.5	0.6	0.7
10								0.2	0.3	0.4	0.5	0.5	0.7	0.7	0.8
7							0.1	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
5						0.1	0.3	0.4	0.5	0.7	0.8	0.8	0.9	1.0	1.1
4					0.1	0.3	0.4	0.5	0.7	0.8	0.9	0.9	1.0	1.1	1.2
3				0.1	0.2	0.4	0.5	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4
2			0.2	0.4	0.5	0.6	0.7	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6
1		0.4	0.6	0.8	0.9	1.0	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
0.5	0.5	0.9	1.1	1.2	1.3	1.5	1.6	1.8	1.9	2.0	2.1	2.2	2.3	2.3	2.4

Time that external dose ends (days)

Table 5. To estimate gross fission product decay from intial time (t_i) to final time (t_f), enter at initial time along the sloping left side of the table. Move to the right and select the value that is above the final time at the bottom of the table. For example, if the initial time is 7 days and the last time is 20 days, the external dose is 0.4 times the integrated does from 10 h (average time of arrival) to 48 h (in Sv), obtained from a fallout map. Errors will be within 10% (for shorter times) to 20% (for longer times) of the solution to the equation:

$$\mathrm{Dose}(t_i,t_f) = 3.12 * \mathrm{Dose}(10,48\ \mathrm{h}) * \left[t_i^{(-0.2)} - t_f^{(-0.2)}\right]$$

where $3.12 = \left[(10/24)^{(-0.2)} - 2^{(-0.2)}\right]^{-1}$

Time (after start of nuclear war) that contaminated water or food is first consumed (days)

First consumed (days)	5	10	20	30	40	50	70	90	120	150	200	300
200												0.0
150											0.1	0.1
120										0.2	0.1	0.1
90									0.2	0.2	0.2	0.1
70								0.3	0.3	0.2	0.2	0.1
50							0.4	0.4	0.3	0.3	0.2	0.1
40						0.5	0.5	0.4	0.4	0.3	0.2	0.2
30					0.6	0.6	0.5	0.5	0.4	0.3	0.3	0.2
20				0.7	0.7	0.6	0.5	0.5	0.4	0.4	0.3	0.2
10			0.8	0.8	0.7	0.7	0.6	0.5	0.4	0.4	0.3	0.2
5		0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.5	0.4	0.3	0.2
1	1.0	0.9	0.9	0.8	0.8	0.7	0.6	0.6	0.5	0.4	0.3	0.2

Time that contaminated food or water is last consumed (days)

Table 6. To estimate decay of Sr-89 from initial time (t_i) to final time (t_f) that water or food is consumed. To use, enter at initial time (in days) along sloping left side of table. Move to right and select value that is above the final time at the bottom of the table. For example, if the initial time is 10 days and the final time is 40 days, the decay factor (DF) is 0.7. Interpolate as necessary. This table is based on the equation:

$$[\exp(-\ln 2 * t_i / 50.5) - \exp(-\ln 2 * t_f / 50.5)] * [\ln 2 * (t_f - t_i) / 50.5]^{-1}$$

Time (after start of nuclear war) that contaminated water or food is first consumed (days)

Initial time (days)	2	3	4	5	7	10	15	20	30	40	50
40											0.0
30										0.1	0.0
20									0.1	0.1	0.1
15								0.2	0.2	0.1	0.1
10							0.3	0.3	0.2	0.2	0.1
7						0.5	0.4	0.3	0.2	0.2	0.1
5					0.6	0.5	0.4	0.4	0.3	0.2	0.2
4				0.7	0.6	0.6	0.5	0.4	0.3	0.2	0.2
3			0.7	0.7	0.7	0.6	0.5	0.4	0.3	0.2	0.2
2		0.8	0.8	0.7	0.7	0.6	0.5	0.4	0.3	0.2	0.2
1	0.9	0.8	0.8	0.8	0.7	0.6	0.5	0.5	0.3	0.3	0.2

Time that contaminated food or water is last consumed (days)

Table 7. To estimate decay of I-131 from initial time (t_i) to final time (t_f) that water or food is consumed. To use, enter at initial time (in days) along sloping left side of table. Move to right and select value that is above the final time at the bottom of the table. For example, if the initial time is 7 days and the final time is 20 days, the decay factor (DF) is 0.3. Interpolate as necessary. This table is based on the equation:

$$[\exp(-\ln 2 * t_i / 8.04) - \exp(-\ln 2 * t_f / 8.04)] * [\ln 2 * (t_f - t_i) / 8.04]^{-1}$$

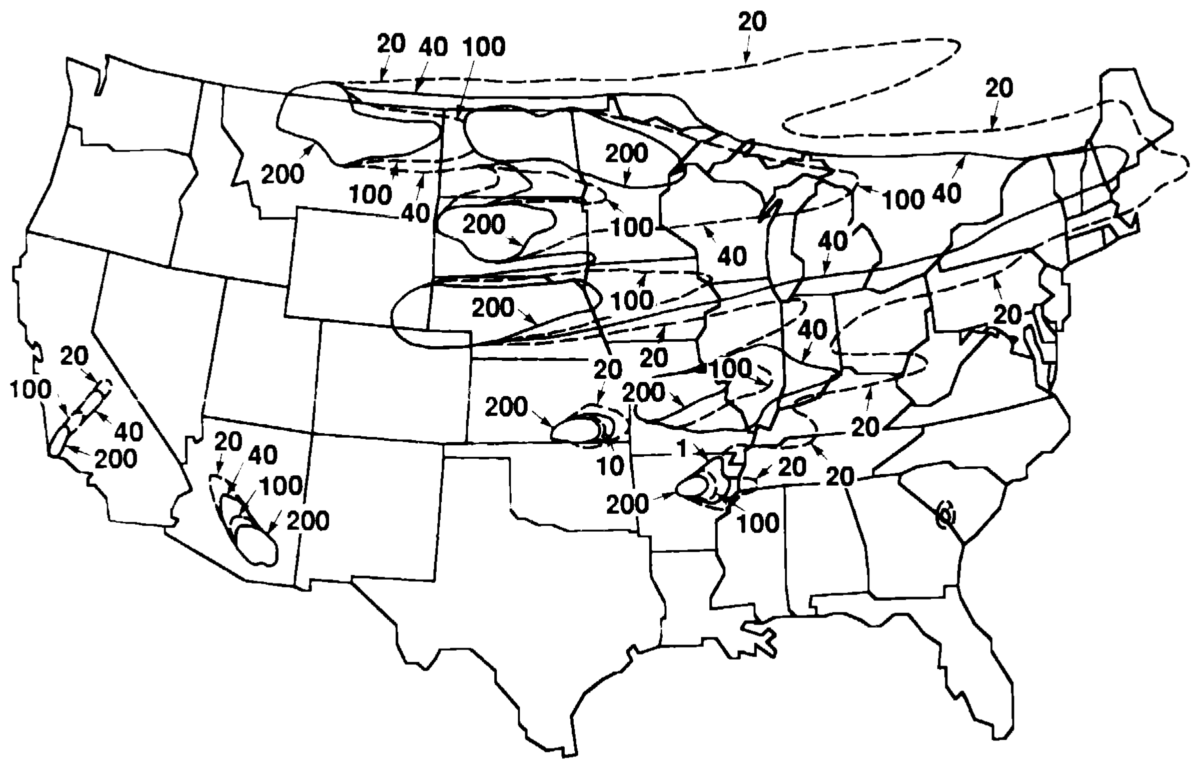

Figure 6: Sr-89 surface deposition contours in MBq/m^2 derived from fallout pattern in Figure 4.

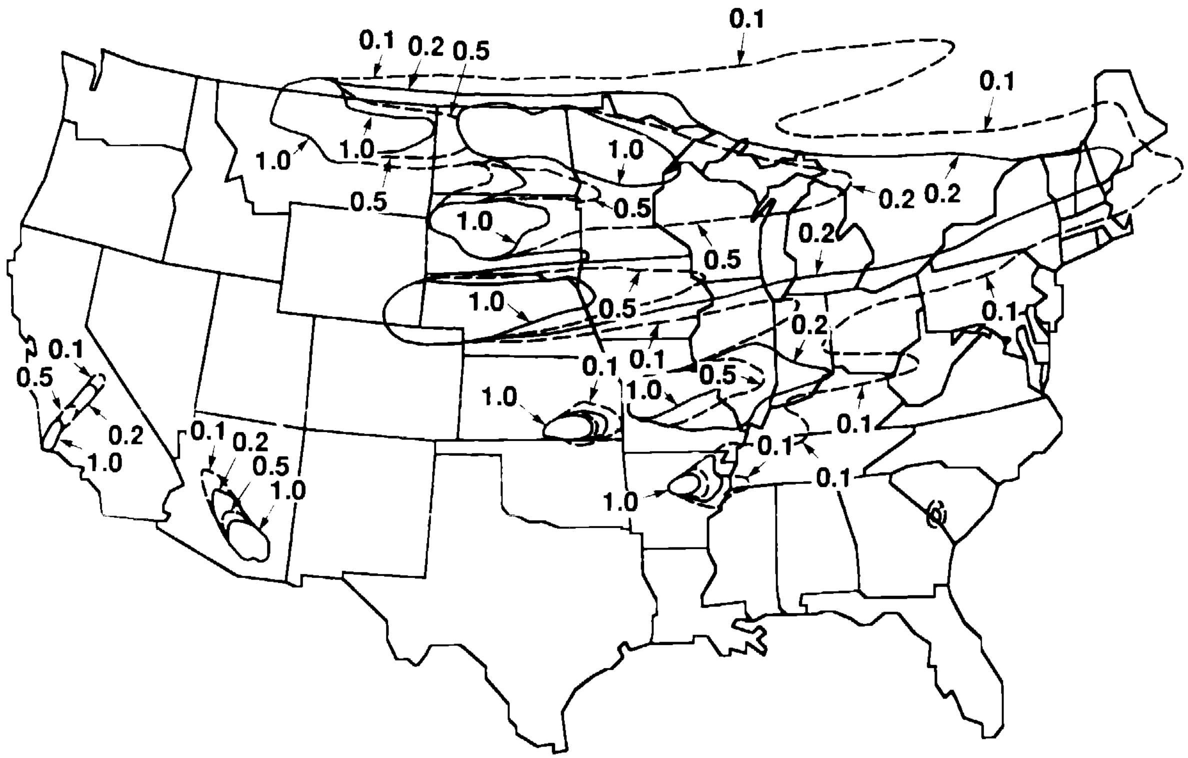

Figure 7: Sr-90 surface deposition contours in MBq/m^2, derived from fallout pattern in Figure 4.

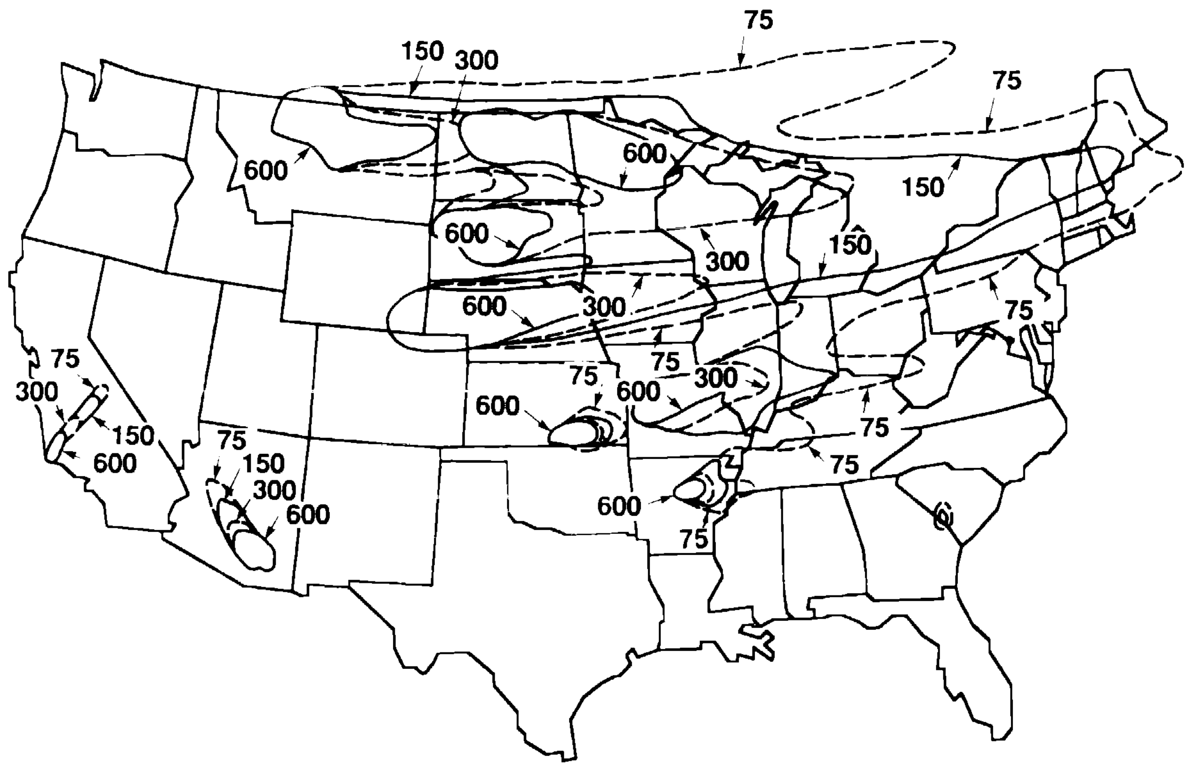

Figure 8: I-131 surface deposition contours in MBq/m^2, derived from fallout pattern in Figure 4.

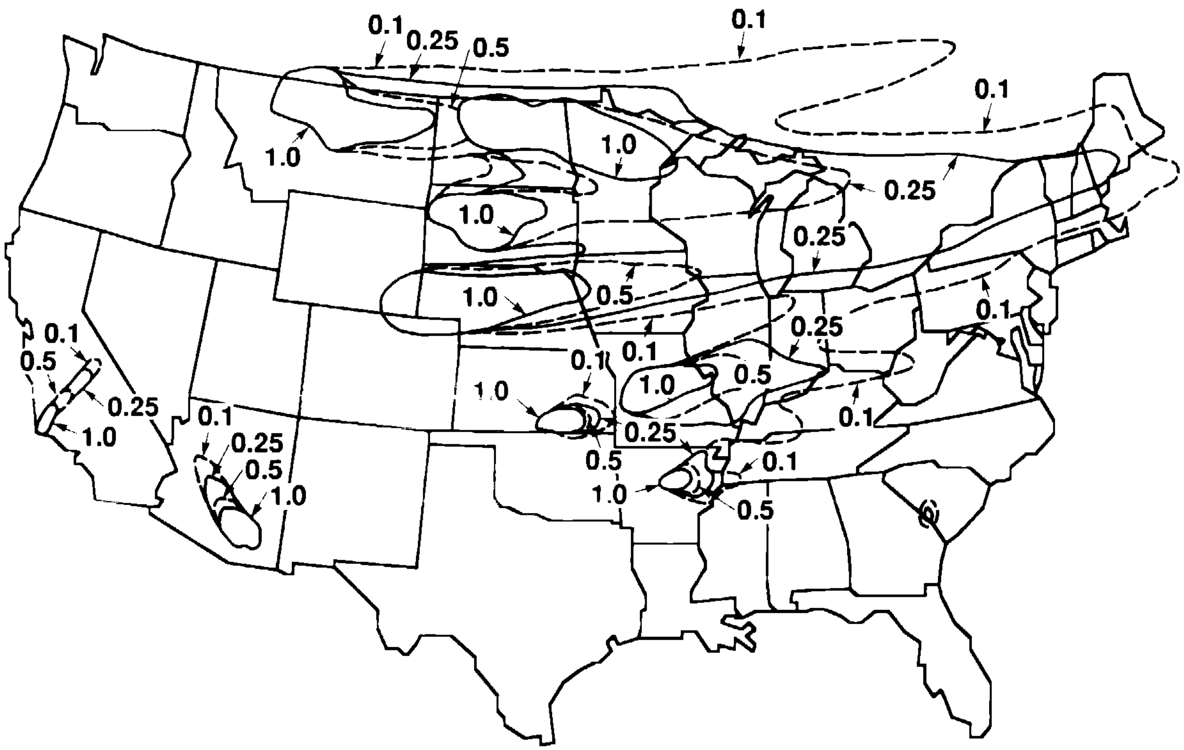

Figure 9: Cs-137 surface deposition contours in MBq/m^2, derived from fallout pattern in Figure 4.

If survivors of a nuclear war could not receive food from a government (or other) distribution center, it is expected that they would barter with farmers and others who might have a plentiful (but probably contaminated) supply of food. With this in mind, we obtained U.S. Department of Agriculture (USDA) computer tapes that list the crops and livestock by year for nearly every county of the United States. We have used these data for the ten locations where we have made internal dose calculations. Figure 10 indicates the crops grown in 1985 within each state. New England and South Dakota provided only state totals of crops to the USDA. Figure 11 shows what livestock were produced in each state; those states with an asterisk reported only state totals. Figure 12 indicates the locations where we have made internal and external dose calculations.

Figure 13 is a graph that is used to estimate the dose depletion factor from the time that it would be safe to leave the refuge for extended periods to 180 days. The equation at the bottom of the figure shows the rate constant (0.02 day^{-1}) that determines the depletion rate. This value is used by the PATHWAY model to estimate percolation into soil [Wh87]. We also assume that it is a reasonable approximation when applied to percolation through residential lawns and soils. To a lesser extent, it would be applicable to paved surfaces in cities and suburbs. There is some evidence that the depletion rate would be less for removal of radionuclides by precipitation; however, the extent and efficacy of decontamination procedures after a nuclear war are unknown. For this reason, we have applied the same rate constant to paved surfaces. Readers, in making their own dose estimates, may enter a different rate constant into the equation at the bottom of Figure 13.

The U.S. counties typically do not report crop and livestock data from small farms. Therefore, in our listings of food available to foragers, we have used the USDA data as a guide but, occasionally, foods have been entered that are not in the USDA databases. Our assumption is that such foods would be available in limited quantities from small farms.

The default values that we have used in making internal dose estimates are given in Table 4. The user should feel free to employ his own values for the listed variables when making entries in the Work Sheet and the supplementary aids in Appendix C. In fact, we have used them ourselves only as guides in our 10 internal and external dose calculations.

SUMMARY AND CONCLUSIONS

We have identified the four significant nuclides that account for nearly three-fourths of the reconstructed total body internal dose to people who lived within a few hundred kilometers of the Nevada Test Site. These are Sr-89, Sr-90, I-131, and Cs-137. Foods considered for internal dose estimates include milk, beef, leafy and non-leafy vegetables, poultry and grain. Except for the I-131 dose to the thyroid, inhalation doses are

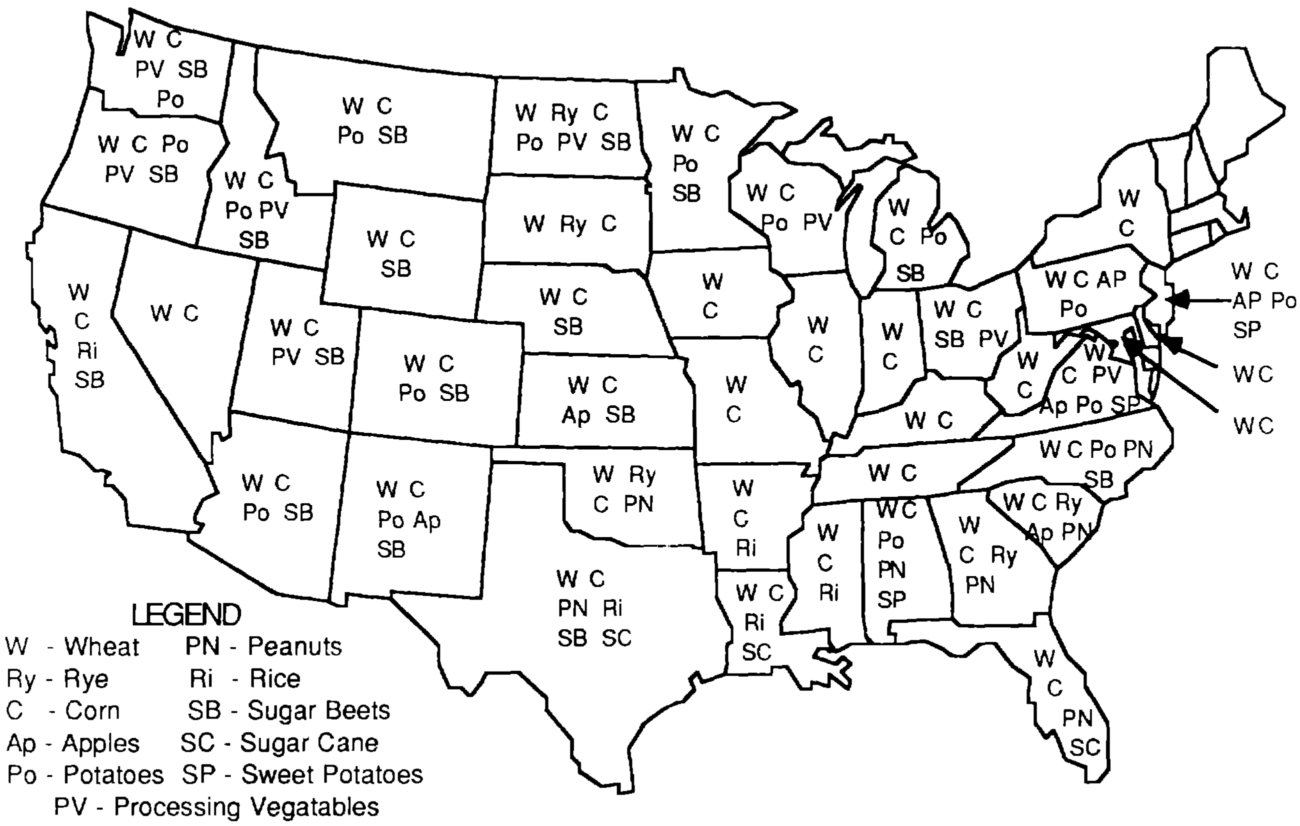

Fig. 10. Types of crops, by states, as reported to the U. S. Department of Agriculure, 1983 - 1986. Tobbacco was the only New Eng- and crop data reported to the USDA during this period.

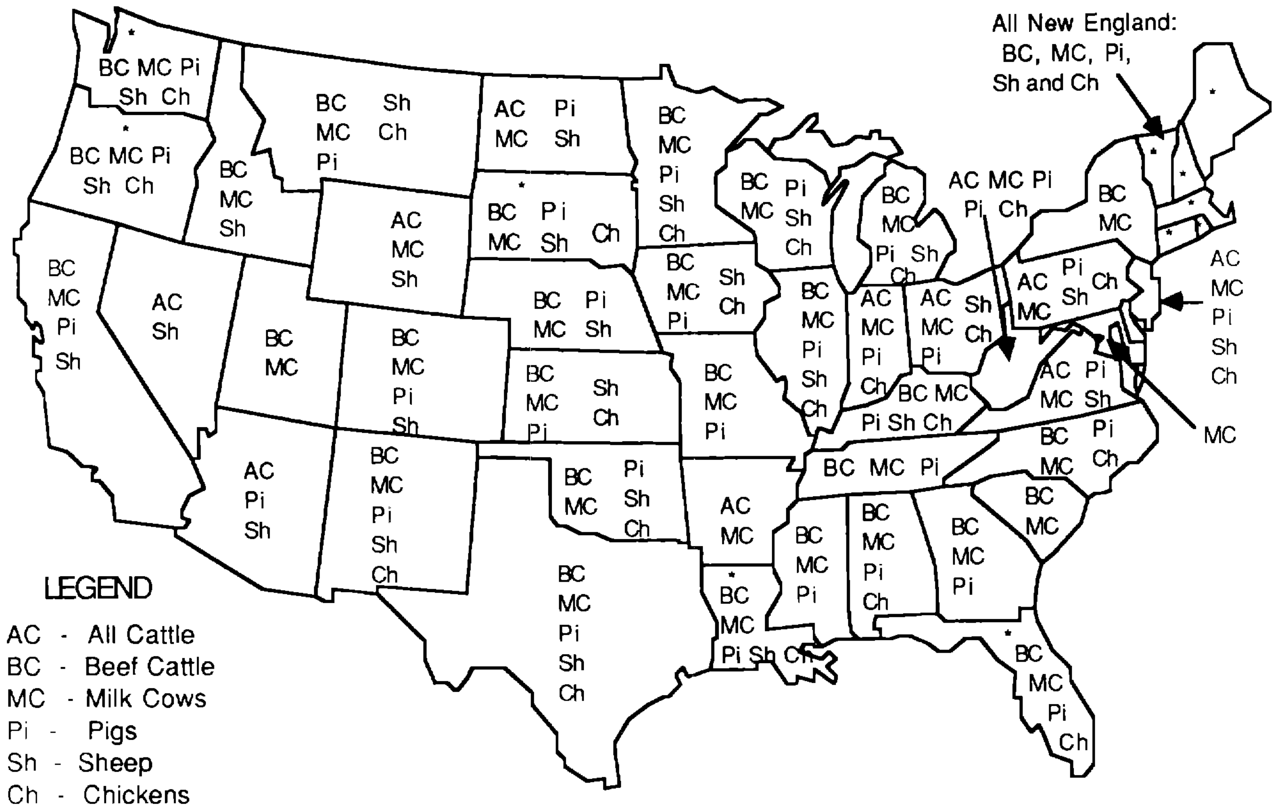

Fig. 11. Types of livestock, by states, as reported to the U. S. Department of Agriculure, 1976 - 1986. An asterisk (*) signifies that only state totals (no county data) are available from the USDA .

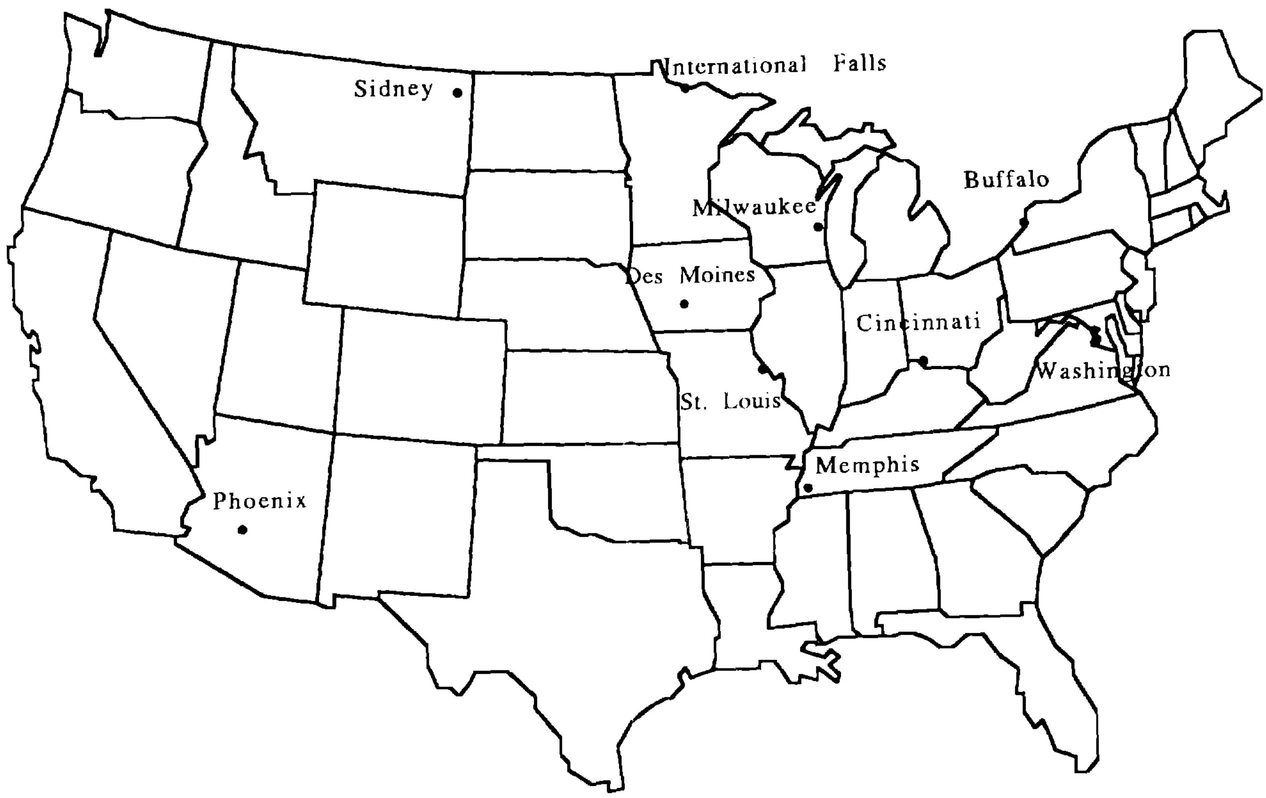

Fig. 12. Locations where detailed internal and external doses that might follow a nuclear war have been calculated.

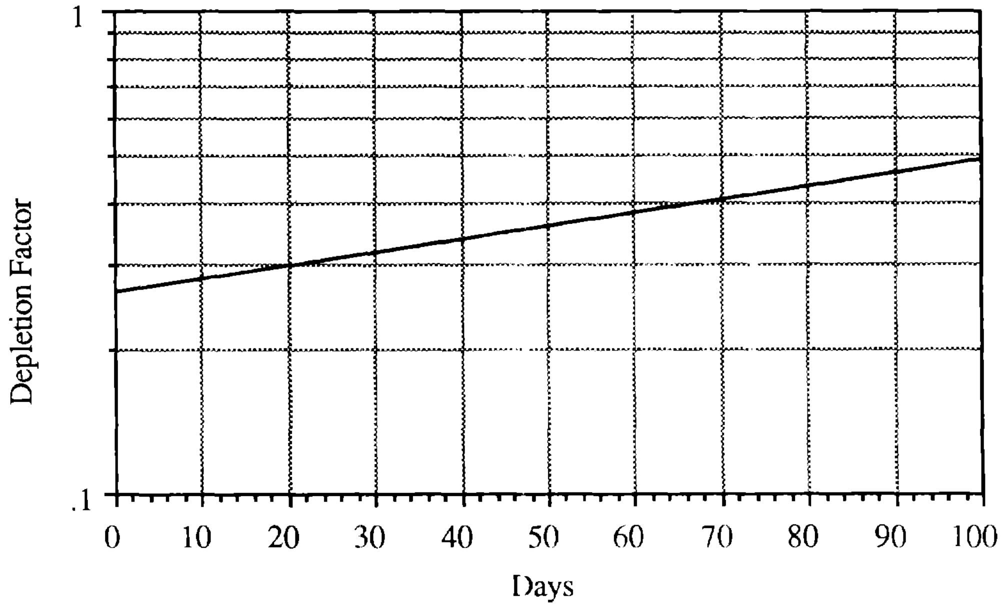

Figure 13. Use this chart to determine the external dose depletion after it is safe to leave the refuge for hours or days at a time. Multiply the intergrated dose received from this time to 180 days (item 20d of the Work Sheet) by the depletion factor. A discussion of how this factor was developed is given in the text. The equation used to construct this graph is:

$$\{ 1 - \exp [-0.02 * (t_f - t_i)] \} * \{0.02 * (t_f - t_i)\}^{-1}$$

insignificant when compared to external doses. Only doses from local fallout have been considered since global fallout would cause relatively small doses. Intermediate fallout, that part of global fallout that is initially placed into the troposphere and removed, principally by rainout and washout within the first few weeks, would be significant only in areas of precipitation where clouds extend high into the troposphere. These areas are spotty and would be small in total area, especially under conditions of reduced precipitation that are expected from the climatic impact of smoke and soot.

From work by Ghan, et al. [Gh87], we have developed U.S. maps that estimate the reductions in temperature, precipitation, and insolation that would be likely after a large scale nuclear war. A U.S. map of local fallout from an attack on the U.S., based on work of Harvey, et al. [Ha87], has been used.

A methodology for estimating doses from ingestion of water and food contaminated by radioactivity has used the PATHWAY model as adapted to the human diets of survivors of a large–scale nuclear war. It is assumed that after such a war, the food transportation system would be disrupted for a period of one to three months. During this time, families would subsist on their own stored food (in the absence of food supplies from the government) for as long as possible. Then they would forage for local water and food obtained from sources such as local farmers, fields, and government distribution centers.

In this study, we use the PATHWAY model, in conjunction with a reasonable hypothetical nuclear attack on the U.S., to arrive at calculations of internal to external dose estimates. Our own calculations are presented with aids that enable readers to use their own nuclear war scenario, fallout pattern, assumptions about the climatic changes brought on by large fires following a nuclear attack, the viability of the transportation system for food delivery, the quality and quantity of water and food available locally, the required caloric intake of the survivors, and several other factors. We intend to develop a computer program to handle the procedures detailed in this report, thereby providing a useful tool that could be quickly applied to large releases of radioactivity, such as occurred during the 1986 Chernobyl disaster.

Using our own input, we have calculated the internal and external doses for 10 locations within the U.S. The case studies have variable external doses, shelter factors, availability of foods from nearby government distribution agencies, other foods available within walking or bicycling distances, and other variables. Our calculations show that the ratios of internal to external dose vary from less zero to 107 percent. Seven of the case studies have ratios less than 10 percent. The higher ratios result from the effects of a large shelter factor (reducing the external dose) and consumption of contaminated foraged food for long periods (increasing the internal dose).

We conclude that the average American family that survived a large-scale nuclear war, using their own home or work place as a refuge, would receive a total internal dose from ingestion that would range from less than one to 10 percent of the total external dose. Those who stayed where shelter protection factors and foraged food consumption rates were large would receive internal doses that are 10% to more than 100% of the total external dose.

ACKNOWLEDGMENTS

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INTERNAL DOSE WORK SHEET

Instructions: This Work Sheet and the accompanying sheets and tables are used to estimate the internal dose via ingestion to an *individual*, following a nuclear attack. With few exceptions, entries should be made to only 2 significant figures.

---

1. Describe the location and type of refuge that a family occupies (this can vary from a tent in a field to a large urban building with several sub–basements). Also, note any structural damage.
   Description: St. Louis, Missouri. Large apartment building in western part of city. No structural damage to this apartment.

2. How many people are sharing the refuge?
   Number: 2

3. How long would the food transportation system be disrupted, leaving available only local sources of food?
   Ans. (days or months): 2 months

4. List sources and quantities (in liters[1]) of potable water and other stored liquids (to be referred to hereafter as "water" with quantities in liters).
   a. Sources: Water heater Toilet tank
   b. Amounts: 176 20 liters
   c. Total amount of stored water: 196 liters.

5. Use of water:
   a. What is the minimum amount of water that *each person* would drink per day?
      Minimum amount: 1.0 liters / day

   b. What is the minimum amount of water that *each person* would use per day for cooking and washing?
      Minimum amount: 0.5 liters / day

   c. Add entries 5a and 5b; multiply the sum by the answer to item 2 This is the total daily water use. Enter below
      Total water use in refuge: 3.0 liters/day

6. Divide item 4c by item 5c to obtain the number of days that stored water would last. Enter below:
   Water in refuge would last 65 days

7. Use of foods:

[1] 1 quart = 0.95 liters; 1 gal. = 3.8 liters.

a. Calculate the minimum number of kilojoules (kJ) or kilocalories (kcal) that *all persons* in the refuge would consume each day. Default values are 7100 kJ (1700 kcal) for an adult or teenage male, 5900 kJ (1400 kcal) for an adult or teenage female, and 4200 kJ (1000 kcal) for male and female children.
Family's min. daily food intake: 3100 ~~kJ~~ or kcal (cross out one).

b. Specify the person (and his or her energy units per day) for which external and internal dose estimates are being calculated. Check one:
Adult or teenage male: ✓ Adult or teenage female: ____ Child: ____

c. Enter the kJ or kcal used per day by person checked above (use values in 7a as a guide).
________ kJ or 1700 kcal

d. Go to Sheet B and list the types and quantities of stored foodstuffs and the total energy value (in kJ or kcal) for each type of food. Refer to Sheet A for the energy value of various foods. Enter the total kJ or kcal of stored food below.
Total energy value: 142,000 ~~kJ~~ or kcal (cross out one).

e. Divide item 7d by item 7a to obtain the number of days that stored food would last. Enter below.
Ans: 46 days

8. If the refuge is reasonably air tight and the stored water and food are covered from fallout, they would not be contaminated by radioactivity. If this is not so, go to Sheet C for water and Sheet E for food; otherwise, go to 9 (below).
   a. Fill in Sheet C, then enter the total dose (in Sv) from a person's ingestion of stored water.
   Amount: 0 Sv

   b. Fill in Sheet E, then enter the total dose (in Sv) for the stored food eaten by a person.
   Amount: 0 Sv

9. Based on the number of days that stored water and food would be available (see answers to items 6 and 7e), how many days after the nuclear war would the stored water and food last, requiring one of the persons in the refuge to forage for water or food?
Forage after: 65 days for water 46 days for food.

10. Using the fallout pattern in Figure 4, or one of your choice,
   a. What would be the total integrated external dose to an unsheltered person from the time of arrival of fallout to 48 h?

External dose from fallout pattern: ___10.___ Sv

b. Using Table 5 (or the equation at the bottom of the table) determine the dose correction factor from time of fallout arrival (our default value is 10/24 days) to the shorter number of days in item 9 (assuming an unsheltered person stays at the same location). Enter the result below.
Dose correction factor: ___2.3___.

c. Multiply 10a times 10b to obtain the external dose for a shelter factor of1.0. Enter below.
External dose for a shelter factor of 1.0: ___23.___ Sv

11. Enter the shelter factor (suggested values are given in Table 4 of the text) and calculate the total integrated external dose to persons while in the refuge up to the time that foraging begins:
a. Shelter factor = ___7.___

b. External dose to persons in refuge up to time when foraging begins (answer to item 10c divided by 11a): ___3.2___ Sv

12. How long would the person on a foraging trip for water or food be outside the refuge?
Ans: ___12___ hours

13. External dose while foraging occurs.
a. Dose to forager:
Calculate the external dose to the person foraging. Use Table 5 (or the equation at the bottom of the table) to make this estimate (multiply tabular value by item 10a).
External dose to forager: ___0.031___ Sv

b. Dose to those who stay in refuge during foraging.
Divide item 13a by item 11a: ___0.0045___ Sv

14. List the types and quantities of foraged water and food on Sheet D Also, list where the food and water were obtained and the relative extent of sheltering from fallout. Then, using Sheet A, calculate the energy value of the foods. Enter the quantity of water and the total kJ or kcal of food below.
a. Quantity of water: ___none___ liters (sufficient stored water)

b. Calculate the time foraged water would last by dividing item 14a by item 5c:___—___days

c. Total energy value of foraged food ___60,600___ ~~kJ~~ or kcal (cross out one).

d. Calculate the time foraged food would last by dividing item 14c by item 7a: ____19____ days

e. Enter how many days have elapsed since the war began [item 9 (value for food) + item 14d]: ____65____ days.

15. Go to Sheet C to estimate the internal dose from drinking foraged water.

16. From item f of Sheet C, enter the internal dose to people from drinking this water:
Dose: ____0.____ Sv

17. Go to Sheet E to estimate the internal dose from consumption of foraged foods.

18. Enter the sum of Total Body doses for all 4 nuclides from the last line of Sheets E-1 (for Sr-89), E-2 (for Sr-90), E-3 (for I-131), and E-4 (for Cs-137).
Total Body dose from consuming foraged food: ____0.32____ Sv

19. Calculate the external dose to an individual, while in the refuge, from the time foraging ended until all the foraged food was consumed.
   a. Using values for days in Sheet E, item 1a as t_i and item 1c as t_f, calculate the external dose using Table 5 (or the equation at the bottom of the table). If table is used, multiply value by item10a. Enter below.
   External dose for a shelter factor of 1.0: ____0.97____ .

   b. External dose while consuming foraged food (item 19a divided by item11a): ____0.14____ Sv.

20. After foraged food or water is consumed, enter an estimate of the total integrated external dose those in a refuge would receive if they left.
   a. Use Table 5 (or the equation at the bottom of the table) to calculate the external dose after the foraged food is consumed; t_i is 14e and t_f is 180 days (multiply tabular value by item 10a). This dose is for a shelter factor of 1.0. Enter value below.
   Additional external dose if refuge is abandoned: ____2.5____ Sv

   b. Multiply the answer above by the external dose depletion factor, using Figure 13. Enter corrected dose below:
   Corrected additional external dose: ____0.98____ Sv

c. At this time, most survivors would spend part of each day in some sort of structure. Enter the fraction of the day that the person selected would have a shelter factor greater than 1.0: ___0.80___.

d. Enter the estimated shelter factor for this fraction of time: ___7___.

e. Calculate the external dose to the person, after resuming a somewhat normal life style. This is: [item 20b * (1 - 20c) + (item 20b * 20c / 20d)]:___0.31___ Sv.

21. Would it be safe to leave the refuge for periods of days or weeks? If yes, go to item 22. If no, it would be necessary to forage again; repeat items 9 to 19, using new values for the second foraging trip.
Ans: ___Yes___ (yes or no)

22. At this time, is the food transportation system reestablished? If not, people will have to depend on water and food available locally. This would result in additional internal doses from water and foods:
Ans: ___Yes___ (yes or no)

23. Summary of internal doses from consuming:
a. stored water (item 8a): ___0.___ Sv
b. stored food (item 8b): ___0.___ Sv
c. foraged water from first trip (item 16): ___0.___ Sv
d. foraged food from first trip (item 18): ___0.32___ Sv
e. foraged water from later trips: ___0.___ Sv
f. foraged food from later trips: ___0.___ Sv
g. after transportation system is reestablished[2]: ___0.___ Sv

h. Total internal dose from all water and food (a to g): ___0.32___ Sv

24. Summary of external doses while:
a. in refuge consuming stored water and food (item 11b): ___3.2___ Sv
b. foraging for water and food[3] the 1st time (item 13a *or* b):___0.031___ Sv
c. further foraging for water and food[3] (item 13a *or* 13b): ___0.___ Sv
d. in refuge consuming foraged water and food (item 19b): ___0.14___ Sv
e. ouside after it is safe to leave refuge (item 20e): ___0.31___ Sv

f. Total external dose (sum of a to e above): ___3.68___ Sv

---

[2] We assume that most of the surviving population would ingest water and food that, if necessary, would be transported from regions with minimal fallout. Readers can make their own assumptions, if desired.

[3] Select item 13b if person does not forage

25. Total internal and external dose (items 23h and 24f): 4.00 Sv

26. Ratio: internal to external doses (items 23h / 24f * 100): 8.0 %

Sheet A
ENERGY VALUES OF FOODS

Food Type	kJ / kg	kcal / lb	Food Type	kJ / kg	kcal / lb
FRUIT			Onions	1590	170
Apples	2430	260	Peas	3520	380
Apple juice	1970	210	Potato chips	23780	2580
Apricots, canned	3600	230	Potatoes, raw	3180	350
Bananas	3560	390	Soybeans, dried	16870	1830
Cantaloups	1260	140	Spinach	1090	120
Cherries	2510	270	Squash, summer	710	80
Dates & Figs, dried	11470	1250	Sweet potatoes	4770	520
Fruit cocktail	3180	350	Tomatoes	920	100
Grapes	2810	310	**NUTS**		
Grapefruit	1630	180	Almonds	25030	2720
Lemons	1130	120	Cashew nuts	23480	2550
Oranges	2050	220	Chestnuts	8920	970
Peaches	1930	210	Hazelnuts	26250	2850
Pears	2550	280	Peanuts	24360	2650
Pineapple juice	2300	250	Pecans	28760	3130
Plums	2090	230	Pistachio nuts	24870	2700
Prunes, dried	10670	1160	Walnuts	27250	2960
Raisins	12100	1320	**CEREAL PRODUCTS**		
Strawberries	1550	170	Breads, various	11300	1230
VEGETABLES			Cornflakes	16120	1750
Asparagus	880	100	Cornstarch	15150	1650
Beans, broccoli	1340	145	Flour, various	14650	1590
Beets	1800	200	Muffins	12310	1340
Cabbage	1090	120	Noodles, dry	15740	1710
Carrots	1670	180	Oatflakes	16200	1760
Corn, sweet	4020	440	Pancakes	9670	1050
Cucumbers	540	60	Popcorn	16160	1760
Dandelion greens	1880	210	Pretzels	16330	1780
Lettuce	590	60	Rice, cooked	4560	500

Sheet A
PAGE 2

Conversion factors:

1 kJ = 0.239 kcal   1 kcal = 4.186 kJ
1.0 kg = 2.20 lb = 35.3 oz
1.0 lb = 16.0 oz = 0.454 kg
1.0 oz = 0.0625 lb = 0.0285 kg
Water: 1 kg = 1 liter = 0.908 qt

Food Type	kJ / kg	kcal / lb	Food Type	kJ / kg	kcal / lb
Spaghetti, dry	15450	1680	Milk, evaporated	5780	630
CONFECTIONERY, SUGAR			Milk, dried, whole	21010	2280
Chocolate, milk	21770	2370	Milk, goat's	2970	320
Cocoa, powder	12520	1360	Milk, sheep's	4480	490
Honey	12730	1380	MEAT, POULTRY		
Jams	11390	1240	Bacon	26160	2840
Maple syrup	10550	1150	Beef, rib or round	8160	890
Molasses	9710	1060	Beef, rump	12680	1380
Sugar, wh. or brn	15910	1730	Beef, sirloin, lean	5990	650
Carb. soft drinks	1930	210	Beef, hamburger	15240	1660
Cola drinks	1630	180	Chicken, fryer	5780	630
Coffee, black	210	20	Chicken, roaster	8250	900
FATS, OILS			Duck	13650	1480
Butter	29970	3260	Goat	6910	750
Corn oil	36960	4020	Goose	14820	1610
Cottonseed oil	36960	4020	Ham, boiled	11260	1220
Lard	37720	4100	Ham, smoked	16280	1770
Margarine	30140	3280	Lamb, chops	14740	1600
Mayonnaise	30060	3270	Lamb, leg	10010	1090
Olive, Peanut, Saf-			Pork, cutlets	14270	1550
flower, Soybean,	36960	4020	Pork, loin	7030	760
Sunflower oils			Pork, chops	13940	1520
DAIRY PRODUCTS, EGGS			Pork, ribs	14690	1600
Cheese, cheddar	16660	1810	Rabbit	6660	720
Cheese, cottage	4440	460	Sausages, beef	11970	1300
Cheese, Parmesan	16450	1790	Sausages, franks	10720	1170
Cheese, Swiss	16660	1810	Sausages, pork	20850	2270
Cream, heavy	12060	1310	Turkey	9130	990
Eggs, whole, raw	6780	740	Veal	6870	680
Milk- cow's whole	2680	290	Venison	5190	560

SHEET B - Energy Value of Stored Foods

Instructions: Enter the types of food stored, the quantity (in kg or lb.), the energy value (in kJ/kg or kilocalories/lb), and the total kJ or kcal for each line. Before totalling the energy values, line out the frozen food that cannot be eaten within a week. If outsiders might forcibly steal some food, line out those items. If more space is needed, go to page 2 of Sheet B.

Type of Food	Quantity of Food		Energy Value		Quantity x Energy Value	
	kg	lbs.	kJ / kg	kcal / lb	kJ	kcal
Apples		12		260		3120
Bananas		8		390		3120
Oranges		10		220		2200
Raisins		1		1320		1320
Beans		5		145		725
Carrots		6		180		1080
Corn		5		440		2200
Lettuce		2		60		120
Peas		6		380		2280
Potato chips		0.5		2580		1290
Sweet Potatoes		3		520		1560
Walnuts		2		2960		5920
Bread		5		1230		6150
Flour		12		1590		19080
Pancakes		1		1050		1050
Rice		5		500		2500
Spaghetti		3		1680		5040
Cocoa		1		1360		1360
Jams		3		1240		3720
Sugar		10		1730		17300
Cola drinks		5		180		900
Butter		2		3260		6520
Corn oil		1		4020		4020
Mayonaise		1		3270		3270
White potatoes		20		350		7000
Olive oil		1		4020		4020
Swiss cheese		1		1810		1810
Eggs		1		740		740

Total Energy Value, this Sheet = 109,415 ~~kJ~~ or kcal (cross out one)

SHEET B - Page 2

Type of Food	Quantity of Food		Energy Value		Quantity x Energy Value	
	kg	lbs.	kJ / kg	kcal / lb	kJ	kcal
Milk		4		290		1160
Bacon		1		2840		2840
Sirloin steak		4		650		2600
Hamburger		3		1660		4980
Chicken		3		630		1890
Ham, boiled		5		1220		6100
Pork chops		4		1520		6080
Frankfurters		6		1170		7020

Total Energy Value, this Sheet = 32,670 ~~kJ~~ or kcal (cross out one)
Sum of Total Energy Value, (pg. 1 and pg. 2) = 142,085 ~~kJ~~ or kcal (cross out one). Enter this value at item 7b on the Work Sheet.

SHEET C
INTERNAL DOSE FROM INGESTION OF WATER

1. Estimate the concentrations (in MBq / m^3) of Sr-89, Sr-90, I-131, and Cs-137 in water to be consumed. If the water is from a reservoir or lake, the concentration can be approximated by assuming that the integrated surface deposition (*DEP*) mixes uniformly throughout the average depth (*D*) of the reservoir.
   Then, the concentration (*C*) is:

$$C \text{ (MBq/m}^3) = DEP \text{ (MBq/m}^2) / D \text{ (m)} \qquad (1)$$

2. The dose from drinking *n* liters of water per day for *p* days is then,

$$Dose \text{ (Sv)} = C \text{ (MBq/m}^3) * DF * 10^{-3} \text{ m}^3\text{/liter} * n \text{ liters/day} * p \text{ days} * q\text{(Sv/MBq)}. \qquad (2)$$

where *DF* is the average decay reduction factor while the foraged water is consumed (see item 3d, below) and *q* is the Total Body effective dose equivalent in Sv for drinking water with 1 MBq of the radionuclides shown in the following table. These values were taken from the Supplement to Part 1 of ICRP 30 [ ].

Nuclide	*q* (Sv/ MBq)
Sr-89	5.5×10^{-3}
Sr-90	3.9×10^{-2}
I-131	1.7×10^{-2}
Cs-137	1.6×10^{-2}

3a. If water is from a reservoir or lake, enter below the estimated values for the integrated surface deposition (DEP_{48}) in MBq /m^2 at H + 48 h (use Figures 6 to 9 in text).

DEP_{48}(MBq/m^2) at H+ 48 h for Sr-89 = ________ Sr-90 = ________
I-131 = ________ Cs-137 = ________
D (m) = ________

b. Calculate values of C (mBq/m^3) for the four nuclides, using Equation (1), or an estimate provided by local officials or others (DEP_{48} divided by D).

Concentrations (C) are
Sr-89 = ______ Sr-90 = ______ I-131 = ______ Cs-137 = ______

c. How were values in 3b. obtained (Equation 1 or local estimate)? ______________________________

d. For Sr-89 and I-131 (half-lives of 50.5 and 8.0 days respectively), radioactive decay must be considered.[1] Enter your values for t_i (from Item 6 of the Work Sheet) and t_f. (refer to item 14b of the Work Sheet).

t_i = ________ days t_f = ________ days

Using Table 6, estimate the Sr-89 decay fractions (DF) from t_i to t_f. Enter the result below. Perform the same calculation for I-131, using Table 7 to calculate the decay fraction:

DF for Sr-89 = ________ DF for I-131 = ________

e. Calculate the internal dose from drinking water using Equation (2) with the values for C, DF, and the following input:
n = ________ liters/day
p = ________ days [note that p is (t_f - t_i) and should be the same as Work Sheet items 6 (stored water) or 14b (foraged water)].

f. Calculate the Total Body doses from Equation 2 (above) Enter the results below.
Sr-89 = _____ Sv Sr-90 = _____ Sv I-131 = _____ Sv Cs-137= _____

g. Sum the four doses and enter below and at item 8a or item 16. of the Work Sheet:
Total internal dose from drinking water = ________ Sv.

h. Go to item 17 of the Work Sheet

[1] A decay correction of 1.0 is valid for Sr-90 and Cs-137 because of their long half lives.

SHEET D

Energy Value of Foraged Water and Food

Instructions: In col. 1, indicate where water and food were obtained (e. g., Govt. Distib. Center, farmer's field). In col. 2, enter whether the water and food are in the open or sheltered. For water, use only the first 3 columns. The last column is the product of the Quantity and Energy Value (per kg or lb) entries. Note: 1 lb. = 0.45 kg.

Water and Type of Food and Where Obtained	Exposure of Water and Food to Radioactivity	Quantity of Water and Food		Energy Value of Food		Quantity times Energy Value	
		kg	lbs.	kJ/kg	kcal/lb.	kJ	kcal
Water* None	needed						
Beef from farm	Cattle on		15		1380		20700
in Platte Co	pasture						
Poultry from	kept in covered		12		630		7560
farmer	building						
Spam from	In sealed cans		7.5		1200		9000
Govt Dist. Center	(not contaminated)						
Corn from	Open field		20		440		8800
Small farm							
Beans from	Open field		12		145		1740
farm							
Spare ribs	Pigs fed in		8		1600		12800
from farmers'	open pasture						
Cooperative							

Total Energy Value, this Sheet = ________ kJ or 60,600 kcal

Total quantity of water (or other potable liquids) obtained = none liters.

* 1 kg of water is equivalent to 1 liter. ** 1 lb. of water = 0.45 liters

SHEET E

INTERNAL DOSE FROM CONSUMING CONTAMINATED FORAGED FOODS

The internal dose via the food pathway to individuals depends on the age and sex of the consumer, types and quantities of foods consumed, the quantity of fallout on the food, the rate of decay of the nuclides, the dose conversion factor (DCF in Sv per MBq / m^2) and, after a nuclear war, the degree of climatic perturbation that might be experienced. For this study, we consider two ages (adult and child), two sexes, the four significant nuclides (Sr-89, Sr-90, I-131, and Cs-137), six (potential) food types, one organ (the Total Body, wherein the doses from individual nuclides can be summed to give a meaningful total), and three degrees of climatic perturbation (that could be brought on by soot and smoke lofted into the atmosphere after a nuclear war). This sheet considers all 4 of the significant nuclides. The sheets that follow (E-1 to E-4) each apply to a specific nuclide

1. Enter how many days *after the start of the war* that the foraged food was obtained, first consumed, and all gone.
   a. Day food was obtained (refer to Work Sheet item 9): 46
   b. Day food was first consumed: 46
   c. Day food was all gone (Work Sheet item 14e): 65

2. Using Tables 6 and 7 (or equations at bottom of tables),input item 1b as t_i and item 1c as t_f. Obtain decay factors for Sr-89 and I-131 and enter below and at item b on tables of E-1 and E-3.
   Decay factor for Sr-89: 0,47 Decay factor for I-131 0.009

3. Energy units needed per day.
   a. On the Work Sheet, Item 7a, the minimum number of energy units per day that *all persons* in the refuge would require was entered. Enter that value below.
   Min. number of energy units: 3100 ~~MJ~~ or kcal (cross out one)

   b. From item 7c of the Work Sheet, enter the energy units per day for the person for which dose estimates are being calculated.
   Person's daily energy units: 1700 ~~MJ~~ or kcal (cross out one).

4. For the food type, enter the fraction by which the DCF would be changed by climatic perturbations. Table 2 may be used as a guide.
   Climatic perturb. factor for Milk: 1.1 Beef: 2.5 Poultry: 1.1
   Leafy veg.: 2.5 Non-leafy veg.: 2.5 Grain: 2.5

5. Fill in the table below (be sure that correct values for item d are selected; the values without parentheses are in *kg/day*, those within parentheses are in *pounds/day*):

		TYPE OF FOOD					
	ITEM	MILK	BEEF	POULTRY	LEAFY VEG.	NON-LEAFY VEG.	GRAIN
a.	Total kg (or lb.) of *each* foraged food (see Sheet D)	—	15 lb beef 8 lb ribs 23 lb	12 lb.	—	32 lb.	—
b.	Work Sheet item 14d (Days foraged food lasts)	—	19	19	—	19	—
c.	Kg.(or lb.) of food per day for person: a/b * 3b/3a	—	0.67	0.35	—	0.93	—
d.	Ave. Daily U.S. Diet kg / day (lb. / day)	Child: 0.623 (0.233) Adult: 0.360 (0.163)	Child: 0.113 (0.060) Adult: 0.277 (0.126)	Child: 0.017 (0.008) Adult: 0.030 (0.014)	Child: 0.021 (0.010) Adult: 0.062 (0.028)	Child: 0.022 (0.010) Adult: 0.025 (0.011)	Child: 0.025 (0.011) Adult: 0.117 (0.053)
e.	Ratio: c / d kg / kg or (lb.) / (lb.)	—	5.3	25.	—	85.	—

6. Go to Sheet E-1 for Sr-89.

Sheet E-1

Internal Dose from Ingestion of Foods with Sr-89

		TYPE OF FOOD					
	ITEM	MILK	BEEF	POULTRY	LEAFY VEG.	NON-LEAFY VEG.	GRAIN
a.	Ratio: c / d from Sheet E, item e	–	5.3	25	-	85.	–
b.	Decay Correction, from Sheet E, Item 2	–	0.47	0.47	–	0.47	–
c.	Climate Pert. factor from Sheet E, Item 4	–	2.5	11	–	2.5	–
d.	Product of Corrections (a x b x c)	–	6.2	13	–	100.	–
e.	DCF- Sv per MBq/sq m, from Table 1 of text	–	3.4×10^{-6}	2.2×10^{-8}	–	1.1×10^{-5}	–
f.	Corrected DCF (d x e)	–	2.1×10^{-5}	2.9×10^{-7}	–	1.1×10^{-3}	-
g.	Integ. Dep. - MBq . sq. m for location. See footnote.	–	180.	180	–	180.	–
h.	Total Body Internal Dose (Sv) (f x g)	–	3.8×10^{-3}	5.2×10^{-5}	-	2.0×10^{-1}	–

Sum of doses for all food types= 2.0×10^{-1} Sv.

*The integrated deposition is obtained by multiplying Work Sheet item 10a by 18. (the conversion value in Table 3 for Sr-89)

Go to Sheet E-2 for Sr-90.

Sheet E-2

Internal Dose from Ingestion of Foods with Sr-90

	ITEM	TYPE OF FOOD: MILK	BEEF	POULTRY	LEAFY VEG.	NON-LEAFY VEG.	GRAIN
a.	Ratio: c / d from Sheet E, item e	-	5.3	25.	-	85.	-
b.	Decay Correction	1.0	1.0	1.0	1.0	1.0	1.0
c.	Climate Pert. factor, from Sheet E Item 4.	-	2.5	1.1	-	2.5	-
d.	Product of Corrections (a x b x c)	-	13.	28.	-	213.	-
e.	DCF- Sv per MBq/sq m, from Table 1 of text	-	6.1×10^{-4}	2.6×10^{-6}	-	8.6×10^{-4}	-
f.	Corrected DCF (d x e)	-	7.9×10^{-3}	7.3×10^{-5}	-	1.8×10^{-2}	-
g.	Integ. Dep. - MBq . sq. m for location. See footnote.	-	1.1	1.1	-	1.1	-
h.	Total Body Internal Dose (Sv) (f x g)	-	8.7×10^{-3}	8.0×10^{-5}	-	2.0×10^{-2}	-

Sum of doses for all food types= 2.9×10^{-2} Sv.

*The integrated deposition is obtained by multiplying Work Sheet item 10a by 0.11 (the conversion value in Table 3 for Sr-90).

Go to Sheet E-3 for I-131.

Sheet E-3

Internal Dose from Ingestion of Foods with I-131

	ITEM	MILK	BEEF	POULTRY	LEAFY VEG.	NON-LEAFY VEG.	GRAIN
		TYPE OF FOOD					
a.	Ratio: c / d from Sheet E, item c	-	5.3	25.	-	85.	-
b.	Decay Correction, from Sheet E, Item 2	-	0.009	0.009	-	0.009	-
c.	Climate Pert. from Sheet E, Item 4	-	2.5	1.1	-	2.5	-
d.	Product of Corrections (a x b x c)	-	0.12	0.25	-	1.9	-
e.	DCF- Sv per MBq/sq m, from Table 1 of text	-	7.1×10^{-7}	2.9×10^{-9}	-	7.5×10^{-7}	-
f.	Corrected DCF (d x e)	-	8.5×10^{-8}	7.3×10^{-10}	-	1.4×10^{-6}	-
g.	Integ. Dep. - MBq . sq. m for location. See footnote.	-	660.	660.	-	660.	-
h.	Total Body Internal Dose (Sv) (f x g)	-	5.6×10^{-5}	4.8×10^{-7}	-	9.2×10^{-4}	-

Sum of doses for all food types= 9.8×10^{-4} Sv.

*The integrated deposition is obtained by multiplying Work Sheet item 10a by 66. (the conversion value in Table 3 for I-131)

Go to Sheet E-4 for Cs-137.

Sheet E-4
Internal Dose from Ingestion of Foods with Cs-137

For Cs-137, enter integrated deposition (MBq/sq. m) where food was obtained

		TYPE OF FOOD					
	ITEM	MILK	BEEF	POULTRY	LEAFY VEG.	NON-LEAFY VEG.	GRAIN
a.	Ratio: c / d from Sheet E, item e	-	5.3	25.	-	85.	-
b.	Decay Correction	1.0	1.0	1.0	1.0	1.0	1.0
c.	Climate Pert. from Sheet E, Item 4	-	2.5	1.1	-	2.5	-
d.	Product of Corrections (a x b x c)	-	13.	28.	-	213.	-
e.	DCF- Sv per MBq/sq m, from Table 1 of text	-	4.6×10^{-3}	2.3×10^{-4}	-	3.6×10^{-5}	-
f.	Corrected DCF (d x e)	-	6.0×10^{-2}	6.4×10^{-3}	-	7.7×10^{-3}	-
g.	Integ. Dep. - MBq . sq. m for location. See footnote.	-	1.2	1.2	-	1.2	-
h.	Total Body Internal Dose (Sv) (f x g)	-	7.2×10^{-2}	7.7×10^{-3}	-	9.2×10^{-3}	-

Sum of doses for all food types= 8.9×10^{-2} Sv.

*The integrated deposition is obtained by multiplying Work Sheet item 10a by 0.12 (the conversion value in Table 3 for Cs-137).

Go to item 18 of the Internal Dose Work Sheet.

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APPENDIX A

Milk Pooling

Milk Pooling

A possibly important factor in internal dose estimation is radioactivity in dairy products. The important transfer mechanism for fallout radioactivity to milk producing domestic animals is fresh pasture grass or green-chopped forage. Hence, the concentration of radioactivity in milk depends on local feeding practices. In addition, since it has become common to "pool" milk from several dairies at a cooperative, the details of the milk distribution system from production to consumption must be considered.

In peacetime, with an intact distribution network in place, these factors can be estimated from the time and space distribution of the fallout, the grazing patterns, and the local daily feeding practices for cows. Then, the milk production locations, distribution sites (including milk pooling), and demographic consumption can be considered. Relevant work on this problem has recently been reported by Ward and Whicker (Wa87) and Dreicer et. al., (Dr87) as part of a program whose goal is to reconstruct internal dose assessments from the atmospheric nuclear weapons tests conducted in the 1950's at the Nevada Test Site in the United States. This assessment involves a complex and time-dependent problem and still is in the model formulation stage; numerical results are not expected until 1989. Clearly, milk pooling is a major factor; the extent of this practice has been increasing with time as farming and distribution practices evolve.

An underlying assumption in the calculations cited above follows from the belief then that the weapons test fallout exposure levels were considered quite low. Hence, no mitigating actions were taken by the exposed population and normal eating and drinking patterns ensued. In a post-nuclear war scenario, this assumption probably would not apply. We anticipate the production, transportation and distribution of milk will be severely affected for an extended time. Radioactivity will be unevenly spread across the country, and milk contamination on a local level will depend on the amount of fallout and local feeding practices. In our internal dose calculations, we assume that distribution of milk to consumers will initially be limited to local (county) sources. Where there are authorities with testing equipment, mitigating actions to avoid contaminated dairy products will undoubtedly be taken. Hence, the numerical results of the Nevada atmospheric tests assessment would not be directly applicable after a nuclear war

In peacetime, milk contamination could be reduced by pooling with relatively uncontaminated milk. In our opinion, this practice will not predominant. Following a nuclear war, it is likely that uncontaminated supplies will be preserved as such, and contaminated (i.e., above the levels considered "safe") will either be discarded or processed into a storable format. Since the half-life of the principal nuclide of interest (I^{131}) is only 8.04 days, storage is a viable option. For the above reasons, we have decided *not* to factor milk pooling into our calculational model here.

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APPENDIX B

Work Sheet calculations of internal
and external doses for 9 locations in the U.S.

Case 2.

Location: Cincinnati, Ohio
Type of refuge: Small efficiency apartment. Shelter factor = 4.
Structural damage: Windows broken on other side of building. No structural damage.
Special circumstances: None

No. of people in refuge: 1

Time that transportation system would be disrupted: 2.5 months.

Time that stored water would last: 19 days.
Kilocalories of stored food: 40,870
Family's min. daily food intake (kcal): 1400
Person for whom dose calculations were made: Adult female.
Time that stored food would last: 29 days.

External dose in refuge while consuming stored water and food (Sv): 0.65
External dose to forager (Sv): 0.017
External dose to non-foragers (Sv): not applicable.

Quantity of foraged water (liters): 55.
Time that foraged water would last: 37 days.

Kilocalories of food foraged: 70,060
Time that foraged food would last: 50 days

Internal dose from consuming foraged water and food (Sv): 0.026
External dose while consuming foraged water and food (Sv): 0.14
External dose to person after transportation system is restored (Sv): 0.056

Total internal dose (Sv): 0.026
Total external dose (Sv): 0.87

Total dose (Sv): 0.90
Ratio of internal to external dose (%): 3.0

Case 3.

Location: Buffalo, New York
Type of refuge: Single family, wood-frame house. No basement. Shelter factor = 3.
Structural damage: None.
Special circumstances: Canadians would help survivors after 1.5 months.

No. of people in refuge: 4

Time that transportation system would be disrupted: 1.5 months.

Time that stored water would last: 50 days
Kilocalories of stored food: 112,800
Family's min. daily food intake (kcal): 5100
Person for whom dose calculations were made: Teenage female
Time that stored food would last: 22 days

External dose in refuge while consuming stored water and food (Sv): 1.5
External dose to forager (Sv): Not applicable.
External dose to non-foragers (Sv): 0.025

Kilocalories of food foraged: 130,900
Time that foraged food would last: 26 days

Internal dose from consuming foraged water and food (Sv): 0.049
External dose while consuming foraged water and food (Sv): 0.21
External dose to person after transportation system is restored (Sv): 0.14

Total internal dose (Sv): 0.049
Total external dose (Sv): 1.9

Total dose (Sv): 1.9
Ratio of internal to external dose (%): 2.6

Case 4.

Location: International Falls, Minn.
Type of refuge: Small hunting and fishing lodge. Shelter factor = 2.5
Structural damage: None
Special circumstances: 3 fisherman are renting well-stocked lodge. After 30 days, Canadians from Winnipeg offer food to survivors and evacuate them to Winnipeg.

No. of people in refuge: 3

Time that transportation system would be disrupted: 1 month.

Time that stored water would last: 67 days
Kilocalories of stored food: 320,000
Family's min. daily food intake (kcal): 5100
Person for whom dose calculations were made: Adult male
Time that stored food would last: 63 days

External dose in refuge while consuming stored water and food (Sv): 2.6
External dose to forager (Sv): None (no foraging)
External dose to non-foragers (Sv): None.

Kilocalories of food foraged: None
Time that foraged food would last: 0 days

Internal dose from consuming foraged water and food (Sv): 0.
External dose while consuming foraged water and food (Sv): 0.
External dose to person after transportation system is restored (Sv): 0.

Total internal dose (Sv): 0.0
Total external dose (Sv): 2.6

Total dose (Sv): 2.6
Ratio of internal to external dose (%): 0.0

Case 5.

Location: Farm near Sidney, Montana (northeast part of state).
Type of refuge: Two-story farmhouse with large basement. Shelter factor = 5.
Structural damage: None.
Special circumstances: Family makes several short foraging trips to adjacent farm buildings and fields. Family has hand pump (to well) inside.

No. of people in refuge: 5

Time that transportation system would be disrupted: 3 months

Time that stored water would last: > 3 months.
Kilocalories of stored food: 406,000
Family's min. daily food intake (kcal): 7900
Person for whom dose calculations were made: Teenage male.
Time that stored food would last: 51 days.

External dose in refuge while consuming stored water and food (Sv): 4.6
External dose to forager (Sv): 0.15
External dose to non-foragers (Sv): 0.03

Kilocalories of food foraged: 355,000
Time that foraged food would last: 42 days.

Internal dose from consuming foraged water and food (Sv): 0.81
External dose while consuming foraged water and food (Sv): 0.33
External dose to person after transportation system is restored (Sv): 0.49

Total internal dose (Sv): 0.81
Total external dose (Sv): 5.6

Total dose (Sv): 6.4
Ratio of internal to external dose (%): 14.5

Case 6.

Location: Memphis, Tenn.
Type of refuge: Sub-basement of large downtown office building. Shelter factor = 200.
Structural damage: Above ground part of building damaged. Basements remain intact.
Special circumstances: Little stored food available. Survivors exist on stored water for first week.

No. of people in refuge: 25

Time that transportation system would be disrupted: 1.5 months.

Time that stored water would last: 15 days.
Kilocalories of stored food: none.
Family's min. daily food intake (kcal): 39,500
Person for whom dose calculations were made: Adult male.
Time that stored food would last: 0 days.

External dose in refuge while consuming stored water and food (Sv): 0.012
External dose to forager (Sv): 0.043
External dose to non-foragers (Sv): All forage.

Kilocalories of food foraged: 948,000
Time that foraged food would last: 24 days.

Internal dose from consuming foraged water and food (Sv): 0.16
External dose while consuming foraged water and food (Sv): 0.003
External dose to person after transportation system is restored (Sv): 0.088

Total internal dose (Sv): 0.16
Total external dose (Sv): 0.15

Total dose (Sv): 0.31
Ratio of internal to external dose (%): 107

Note: if officer worker moved to New Orleans 46 days after the nuclear war began, his total internal dose would be the same, but his external dose would decrease to 0.063 Sv. The ratio of internal to external dose would increase to 250%.

Case 7.

Location: Phoenix, Arizona.
Type of refuge: Retirement condominium with 50 units. Shelter factor = 2.
Structural damage: None.
Special circumstances: Meals are normally served in a large dining hall, but each condominium has a small kitchen. Area of fallout is relatively small; other nearby residents come to aid of these people after 30 days.

No. of people in refuge: 85 (35 male and 40 female residents plus staff of 10).

Time that transportation system would be disrupted: 1 month

Time that stored water would last: 31 days.
Kilocalories of stored food: 1,050,000 (large kitchen), 220,000 (couple's kitchen).
Family's min. daily food intake (kcal): 131,000 for all residents.
Person for whom dose calculations were made: Adult female
Time that stored food would last: 20 days.

External dose in refuge while consuming stored water and food (Sv): 2.0
External dose to forager (Sv): 0.03
External dose to non-foragers (Sv): 0.01

Kilocalories of food foraged: 30,500
Time that foraged food would last: 10 days

Internal dose from consuming foraged water and food (Sv): 0.16
External dose while consuming foraged water and food (Sv): 0.11
External dose to person after transportation system is restored (Sv): 0.18

Total internal dose (Sv): 0.16
Total external dose (Sv): 2.3

Total dose (Sv): 2.5
Ratio of internal to external dose (%): 7.0

Case 8.

Location: Suburbs of Washington, D.C.
Type of refuge: Two-story, single family home with full basement. Shelter factor = 2.
Structural damage: Blast broke windows on north and east sides. Repaired with plywood sheets, tape and nails before fallout arrived.

Special circumstances: Fallout relatively light. Several trips made for water and food.

No. of people in refuge: 4

Time that transportation system would be disrupted: 3 months.

Time that stored water would last: 26 days.
Kilocalories of stored food: 177,000
Family's min. daily food intake (kcal): 5500
Person for whom dose calculations were made: Teenage female.
Time that stored food would last: 32 days.

External dose in refuge while consuming stored water and food (Sv): 0.32
External dose to forager (Sv): 0.004
External dose to non-foragers (Sv): 0.002

Kilocalories of food foraged: 353,000
Time that foraged food would last: 64 days.

Internal dose from consuming foraged water and food (Sv): 0.016
External dose while consuming foraged water and food (Sv): 0.054
External dose to person after transportation system is restored (Sv): 0.015

Total internal dose (Sv): 0.016
Total external dose (Sv): 0.392

Total dose (Sv): 0.408
Ratio of internal to external dose (%): 4.1

Case 9.

Location: Milwaukee, Wisconsin
Type of refuge: One-story, single family house in western suburbs. Shelter factor =100.
Structural damage: Considerable damage from thermal and blast effects.
Special circumstances: Family is in fallout shelter in back yard when war starts.

No. of people in refuge: 3

Time that transportation system would be disrupted: 1.5 months.

Time that stored water would last: 51 days.
Kilocalories of stored food: 127,000
Family's min. daily food intake (kcal): 4100
Person for whom dose calculations were made: Child.
Time that stored food would last: 31 days.

External dose in refuge while consuming stored water and food (Sv): 0.075
External dose to forager (Sv): 0.018
External dose to non-foragers (Sv): 0.0002 (child does not forage).

Kilocalories of food foraged: 82,300
Time that foraged food would last: 20 days.

Internal dose from consuming foraged water and food (Sv): 0.132
External dose while consuming foraged water and food (Sv): 0.0052
External dose to person after transportation system is restored (Sv): 0.20

Total internal dose (Sv): 0.132
Total external dose (Sv): 0.280

Total dose (Sv): 0.41
Ratio of internal to external dose (%): 47

Note: If family moved after 1.5 months to a region that received negligible fallout, the ratio of internal to external dose would be 160%.

Case 10.

Location: Des Moines, Iowa,
Type of refuge: 26-foot motor home in outskirts of Des Moines at the start of the war.
Shelter factor = 1.5
Structural damage: None. No EMP effects.
Special circumstances: After 4 days, the family's radio reports that fallout levels would be much lower 150 km to the south. Family arrives in north-central Missouri on the 5th day.

No. of people in refuge: 3

Time that transportation system would be disrupted: 2 months.

Time that stored water would last: 22 days.
Kilocalories of stored food: 20,800
Family's min. daily food intake (kcal): 4100
Person for whom dose calculations were made: Child
Time that stored food would last: 5 days

External dose in refuge while consuming stored water and food (Sv): 1.8
External dose while driving south to north-central Missouri (Sv): 0.2
External dose to forager (Sv): Not applicable
External dose to non-foragers (Sv): 0.002

Kilocalories of food foraged:
Time that foraged food would last:

Internal dose from consuming foraged water and food (Sv): 0.0062
External dose while consuming foraged water and food (Sv): 0.053
External dose to person after transportation system is restored (Sv): 0.0076

Total internal dose (Sv): 0.0062
Total external dose (Sv): 1.87

Total dose (Sv): 1.87
Ratio of internal to external dose (%): 0.33

APPENDIX C

(Blank copies of Work Sheet and other sheets to enable the readers to make their own internal and external dose estimates)

INTERNAL DOSE WORK SHEET

Instructions: This Work Sheet and the accompanying sheets and tables are used to estimate the internal dose via ingestion to an *individual*, following a nuclear attack. With few exceptions, entries should be made to only 2 significant figures.

---

1. Describe the location and type of refuge that a family occupies (this can vary from a tent in a field to a large urban building with several sub-basements). Also, note any structural damage.
   Description: ____
   ____

2. How many people are sharing the refuge?
   Number: _______

3. How long would the food transportation system be disrupted, leaving available only local sources of food?
   Ans. (days or months): __________

4. List sources and quantities (in liters[1]) of potable water and other stored liquids (to be referred to hereafter as "water" with quantities in liters).
   a. Sources: ____
   b. Amounts: ____ liters
   c. Total amount of stored water: _______________ liters.

5. Use of water:
   a. What is the minimum amount of water that *each person* would drink per day?
      Minimum amount: ________ liters / day

   b. What is the minimum amount of water that *each person* would use per day for cooking and washing?
      Minimum amount: ________ liters / day

   c. Add entries 5a and 5b; multiply the sum by the answer to item 2
      This is the total daily water use. Enter below
      Total water use in refuge: __________ liters/day

6. Divide item 4c by item 5c to obtain the number of days that stored water would last. Enter below:
   Water in refuge would last __________ days

7. Use of foods:

[1] 1 quart = 0.95 liters; 1 gal. = 3.8 liters.

a. Calculate the minimum number of kilojoules (kJ) or kilocalories (kcal) that *all persons* in the refuge would consume each day. Default values are 7100 kJ (1700 kcal) for an adult or teenage male, 5900 kJ (1400 kcal) for an adult or teenage female, and 4200 kJ (1000 kcal) for male and female children.
Family's min. daily food intake: __________ kJ or kcal (cross out one).

b. Specify the person (and his or her energy units per day) for which external and internal dose estimates are being calculated. Check one:
Adult or teenage male: ___ Adult or teenage female: ___ Child: ___

c. Enter the kJ or kcal used per day by person checked above (use values in 7a as a guide).
_________ kJ or ________ kcal

d. Go to Sheet B and list the types and quantities of stored foodstuffs and the total energy value (in kJ or kcal) for each type of food. Refer to Sheet A for the energy value of various foods. Enter the total kJ or kcal of stored food below.
Total energy value: __________________ kJ or kcal (cross out one).

e. Divide item 7d by item 7a to obtain the number of days that stored food would last. Enter below.
Ans: _________ days

8. If the refuge is reasonably air tight and the stored water and food are covered from fallout, they would not be contaminated by radioactivity. If this is not so, go to Sheet C for water and Sheet E for food; otherwise, go to 9 (below).
   a. Fill in Sheet C, then enter the total dose (in Sv) from a person's ingestion of stored water.
   Amount: __________ Sv

   b. Fill in Sheet E, then enter the total dose (in Sv) for the stored food eaten by a person.
   Amount: __________ Sv

9. Based on the number of days that stored water and food would be available (see answers to items 6 and 7e), how many days after the nuclear war would the stored water and food last, requiring one of the persons in the refuge to forage for water or food?
Forage after: ________ days for water _______ days for food.

10. Using the fallout pattern in Figure 4, or one of your choice,
   a. What would be the total integrated external dose to an unsheltered person from the time of arrival of fallout to 48 h?

External dose from fallout pattern: ________ Sv

b. Using Table 5 (or the equation at the bottom of the table) determine the dose correction factor from time of fallout arrival (our default value is 10/24 days) to the shorter number of days in item 9 (assuming an unsheltered person stays at the same location). Enter the result below.
Dose correction factor: _________.

c. Multiply 10a times 10b to obtain the external dose for a shelter factor of1.0. Enter below.
External dose for a shelter factor of 1.0: ________ Sv

11. Enter the shelter factor (suggested values are given in Table 4 of the text) and calculate the total integrated external dose to persons while in the refuge up to the time that foraging begins:
a. Shelter factor = ___________

b. External dose to persons in refuge up to time when foraging begins (answer to item 10c divided by 11a): _________ Sv

12. How long would the person on a foraging trip for water or food be outside the refuge?
Ans: __________ hours

13. External dose while foraging occurs
a. Dose to forager:
Calculate the external dose to the person foraging. Use Table 5 (or the equation at the bottom of the table) to make this estimate (multiply tabular value by item 10a).
External dose to forager: ____________ Sv

b. Dose to those who stay in refuge during foraging.
Divide item 13a by item 11a: _________ Sv

14. List the types and quantities of foraged water and food on Sheet D Also, list where the food and water were obtained and the relative extent of sheltering from fallout. Then, using Sheet A, calculate the energy value of the foods. Enter the quantity of water and the total kJ or kcal of food below.
a. Quantity of water: _______________ liters

b. Calculate the time foraged water would last by dividing item 14a by item 5c:____________days

c. Total energy value of foraged food: ___________ kJ or kcal (cross out one).

d. Calculate the time foraged food would last by dividing item 14c by item 7a: ____________ days

e. Enter how many days have elapsed since the war began [item 9 (value for food) + item 14d]: ____________ days.

15. Go to Sheet C to estimate the internal dose from drinking foraged water.

16. From item f of Sheet C, enter the internal dose to people from drinking this water:
Dose: ____________ Sv

17. Go to Sheet E to estimate the internal dose from consumption of foraged foods.

18. Enter the sum of Total Body doses for all 4 nuclides from the last line of Sheets E-1 (for Sr-89), E-2 (for Sr-90), E-3 (for I-131), and E-4 (for Cs-137).
Total Body dose from consuming foraged food: ____________ Sv

19. Calculate the external dose to an individual, while in the refuge, from the time foraging ended until all the foraged food was consumed.
   a. Using values for days in Sheet E, item 1a as t_i and item 1c as t_f, calculate the external dose using Table 5 (or the equation at the bottom of the table). If table is used, multiply value by item10a. Enter below.
   External dose for a shelter factor of 1.0: ____________ .

   b. External dose while consuming foraged food (item 19a divided by item11a): ____________ Sv.

20. After foraged food or water is consumed, enter an estimate of the total integrated external dose those in a refuge would receive if they left.
   a. Use Table 5 (or the equation at the bottom of the table) to calculate the external dose after the foraged food is consumed; t_i is 14e and t_f is 180 days (multiply tabular value by item 10a). This dose is for a shelter factor of 1.0. Enter value below.
   Additional external dose if refuge is abandoned: ____________ Sv

   b. Multiply the answer above by the external dose depletion factor, using Figure 13. Enter corrected dose below:
   Corrected additional external dose: ____________ Sv

c. At this time, most survivors would spend part of each day in some sort of structure. Enter the fraction of the day that the person selected would have a shelter factor greater than 1.0: _________.

d. Enter the estimated shelter factor for this fraction of time: _____.

e. Calculate the external dose to the person. after resuming a somewhat normal life style. This is [item 20b * (1 - 20c) + (item 20b * 20c / 20d)]:_________ Sv.

21. Would it be safe to leave the refuge for periods of days or weeks? If yes, go to item 22. If no, it would be necessary to forage again; repeat items 9 to 19, using new values for the second foraging trip. Ans: ____________ (yes or no)

22. At this time, is the food transportation system reestablished? If not, people will have to depend on water and food available locally. This would result in additional internal doses from water and foods:
Ans: ____________ (yes or no)

23. Summary of internal doses from consuming:
a. stored water (item 8a): __________________________ Sv
b. stored food (item 8b): ___________________________ Sv
c. foraged water from first trip (item 16): _____________ Sv
d. foraged food from first trip (item 18): ______________ Sv
e. foraged water from later trips: ____________________ Sv
f. foraged food from later trips: _____________________ Sv
g. after transportation system is reestablished[2]: ________ Sv

h.Total internal dose from all water and food (a to g): ________Sv

24. Summary of external doses while:
a. in refuge consuming stored water and food (item 11b): ________ Sv
b. foraging for water and food[3] the 1st time (item 13a *or* b):_____ Sv
c. further foraging for water and food[3] (item 13a *or* 13b): _______ Sv
d. in refuge consuming foraged water and food (item 19b): _______ Sv
e. ouside after it is safe to leave refuge (item 20e): _______________ Sv

f. Total external dose (sum of a to e above): _________ Sv

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[2] We assume that most of the surviving population would ingest water and food that, if necessary, would be transported from regions with minimal fallout. Readers can make their own assumptions, if desired.

[3] Select item 13b if person does not forage.

25. Total internal and external dose (items 23h and 24f): ________ Sv

26. Ratio: internal to external doses (items 23h / 24f * 100): ______ %

Sheet A
ENERGY VALUES OF FOODS

Food Type	kJ / kg	kcal / lb	Food Type	kJ / kg	kcal / lb
FRUIT			Onions	1590	170
Apples	2430	260	Peas	3520	380
Apple juice	1970	210	Potato chips	23780	2580
Apricots, canned	3600	230	Potatoes, raw	3180	350
Bananas	3560	390	Soybeans, dried	16870	1830
Cantaloups	1260	140	Spinach	1090	120
Cherries	2510	270	Squash, summer	710	80
Dates & Figs, dried	11470	1250	Sweet potatoes	4770	520
Fruit cocktail	3180	350	Tomatoes	920	100
Grapes	2810	310	**NUTS**		
Grapefruit	1630	180	Almonds	25030	2720
Lemons	1130	120	Cashew nuts	23480	2550
Oranges	2050	220	Chestnuts	8920	970
Peaches	1930	210	Hazelnuts	26250	2850
Pears	2550	280	Peanuts	24360	2650
Pineapple juice	2300	250	Pecans	28760	3130
Plums	2090	230	Pistachio nuts	24870	2700
Prunes, dried	10670	1160	Walnuts	27250	2960
Raisins	12100	1320	**CEREAL PRODUCTS**		
Strawberries	1550	170	Breads, various	11300	1230
VEGETABLES			Cornflakes	16120	1750
Asparagus	880	100	Cornstarch	15150	1650
Beans, broccoli	1340	145	Flour, various	14650	1590
Beets	1800	200	Muffins	12310	1340
Cabbage	1090	120	Noodles, dry	15740	1710
Carrots	1670	180	Oatflakes	16200	1760
Corn, sweet	4020	440	Pancakes	9670	1050
Cucumbers	540	60	Popcorn	16160	1760
Dandelion greens	1880	210	Pretzels	16330	1780
Lettuce	590	60	Rice, cooked	4560	500

Sheet A
Page 2

Conversion factors:
1 kJ = 0.239 kcal   1 kcal = 4.186 kJ
1.0 kg = 2.20 lb = 35.3 oz
1.0 lb = 16.0 oz = 0.454 kg
1.0 oz = 0.0625 lb = 0.0285 kg
Water: 1 kg = 1 liter = 0.908 qt.

Food Type	kJ / kg	kcal / lb	Food Type	kJ / kg	kcal / lb
Spaghetti, dry	15450	1680	Milk, evaporated	5780	630
CONFECTIONERY, SUGAR			Milk, dried, whole	21010	2280
Chocolate, milk	21770	2370	Milk, goat's	2970	320
Cocoa, powder	12520	1360	Milk, sheep's	4480	490
Honey	12730	1380	MEAT, POULTRY		
Jams	11390	1240	Bacon	26160	2840
Maple syrup	10550	1150	Beef, rib or round	8160	890
Molasses	9710	1060	Beef, rump	12680	1380
Sugar, wh. or brn	15910	1730	Beef, sirloin, lean	5990	650
Carb. soft drinks	1930	210	Beef, hamburger	15240	1660
Cola drinks	1630	180	Chicken, fryer	5780	630
Coffee, black	210	20	Chicken, roaster	8250	900
FATS, OILS			Duck	13650	1480
Butter	29970	3260	Goat	6910	750
Corn oil	36960	4020	Goose	14820	1610
Cottonseed oil	36960	4020	Ham, boiled	11260	1220
Lard	37720	4100	Ham, smoked	16280	1770
Margarine	30140	3280	Lamb, chops	14740	1600
Mayonnaise	30060	3270	Lamb, leg	10010	1090
Olive, Peanut, Saf-			Pork, cutlets	14270	1550
flower, Soybean,	36960	4020	Pork, loin	7030	760
Sunflower oils			Pork, chops	13940	1520
DAIRY PRODUCTS, EGGS			Pork, ribs	14690	1600
Cheese, cheddar	16660	1810	Rabbit	6660	720
Cheese, cottage	4440	460	Sausages, beef	11970	1300
Cheese, Parmesan	16450	1790	Sausages, franks	10720	1170
Cheese, Swiss	16660	1810	Sausages, pork	20850	2270
Cream, heavy	12060	1310	Turkey	9130	990
Eggs, whole, raw	6780	740	Veal	6870	680
Milk- cow's whole	2680	290	Venison	5190	560

SHEET B - Energy Value of Stored Foods

Instructions: Enter the types of food stored, the quantity (in kg or lb.), the energy value (in kJ/kg or kilocalories/lb), and the total kJ or kcal for each line. Before totalling the energy values, line out the frozen food that cannot be eaten within a week. If outsiders might forcibly steal some food, line out those items. If more space is needed, go to page 2 of Sheet B.

Type of Food	Quantity of Food		Energy Value		Quantity x Energy Value	
	kg	lbs.	kJ / kg	kcal / lb	kJ	kcal

Total Energy Value, this Sheet = ______________ kJ or kcal (cross out one)

SHEET B - Page 2

Type of Food	Quantity of Food		Energy Value		Quantity x Energy Value	
	kg	lbs.	kJ / kg	kcal / lb	kJ	kcal

Total Energy Value, this Sheet = ___________ kJ or kcal (cross out one)
Sum of Total Energy Value, (pg. 1 and pg. 2) = ___________ kJ or kcal (cross out one). Enter this value at item 7b on the Work Sheet.

SHEET C
INTERNAL DOSE FROM INGESTION OF WATER

1. Estimate the concentrations (in MBq / m^3) of Sr-89, Sr-90, I-131, and Cs-137 in water to be consumed. If the water is from a reservoir or lake, the concentration can be approximated by assuming that the integrated surface deposition (DEP) mixes uniformly throughout the average depth (D) of the reservoir.
   Then, the concentration (C) is:

$$C\ (\mathrm{MBq/m^3}) = DEP\ (\mathrm{MBq/m^2}) \,/\, D\ (\mathrm{m}) \qquad (1)$$

2. The dose from drinking n liters of water per day for p days is then,

$$Dose\ (\mathrm{Sv}) = C\ (\mathrm{MBq/m^3}) * DF * 10^{-3}\ \mathrm{m^3/liter} * n\ \mathrm{liters/day} * p\ \mathrm{days} * q(\mathrm{Sv/MBq}). \qquad (2)$$

where DF is the average decay reduction factor while the foraged water is consumed (see item 3d, below) and q is the Total Body effective dose equivalent in Sv for drinking water with 1 MBq of the radionuclides shown in the following table. These values were taken from the Supplement to Part 1 of ICRP 30 [ ].

Nuclide	q (Sv/ MBq)
Sr-89	5 5 X 10^{-3}
Sr-90	3 9 X 10^{-2}
I-131	1 7 X 10^{-2}
Cs-137	1 6 X 10^{-2}

3a. If water is from a reservoir or lake, enter below the estimated values for the integrated surface deposition (DEP_{48}) in MBq /m^2 at H + 48 h (use Figures 6 to 9 in text).

DEP_{48}(MBq/m^2) at H+ 48 h for Sr-89 = ________ Sr-90 = ________
I-131 = ________ Cs-137 = ________
D (m) = ________

b. Calculate values of C (mBq/m^3) for the four nuclides, using Equation (1), or an estimate provided by local officials or others (DEP_{48} divided by D).

Concentrations (C) are
Sr-89 = ______ Sr-90 = ______ I-131 = ______ Cs-137 = ______

c. How were values in 3b. obtained (Equation 1 or local estimate)? ______________________________

d. For Sr-89 and I-131 (half-lives of 50.5 and 8.0 days respectively), radioactive decay must be considered.[1] Enter your values for t_i (from Item 6 of the Work Sheet) and t_f. (refer to item 14b of the Work Sheet).

t_i = ________ days t_f = ________ days

Using Table 6, estimate the Sr-89 decay fractions (DF) from t_i to t_f. Enter the result below. Perform the same calculation for I-131, using Table 7 to calculate the decay fraction:

DF for Sr-89 = ________ DF for I-131 = ________

e. Calculate the internal dose from drinking water using Equation (2) with the values for C, DF, and the following input:
n = ________ liters/day
p = ________ days [note that p is (t_f - t_i) and should be the same as Work Sheet items 6 (stored water) or 14b (foraged water)].

f. Calculate the Total Body doses from Equation 2 (above) Enter the results below.
Sr-89 = ____ Sv Sr-90 = ____ Sv I-131 = ____ Sv Cs-137= ____

g. Sum the four doses and enter below and at item 8a or item 16. of the Work Sheet:
Total internal dose from drinking water = ________ Sv.

h. Go to item 17 of the Work Sheet.

[1] A decay correction of 1.0 is valid for Sr-90 and Cs-137 because of their long half lives.

SHEET D

Energy Value of Foraged Water and Food

Instructions: In col. 1, indicate where water and food were obtained (e. g., Govt. Distib. Center, farmer's field). In col. 2, enter whether the water and food are in the open or sheltered. For water, use only the first 3 columns. The last column is the product of the Quantity and Energy Value (per kg or lb) entries. Note: 1 lb. = 0.45 kg.

Water andType of Food and Where Obtained	Exposure of Water and Food to Radioactivity	Quantity of Water and Food		Energy Value of Food		Quantity times Energy Value	
		kg	lbs	kJ/kg	kcal/lb.	kJ	kcal
Water*							

Total Energy Value, this Sheet = __________ kJ or __________ kcal

Total quantity of water (or other potable liquids) obtained = __________ liters.

* 1 kg of water is equivalent to 1 liter. ** 1 lb. of water = 0.45 liters

SHEET E

INTERNAL DOSE FROM CONSUMING CONTAMINATED FORAGED FOODS

The internal dose via the food pathway to individuals depends on the age and sex of the consumer, types and quantities of foods consumed, the quantity of fallout on the food, the rate of decay of the nuclides, the dose conversion factor (DCF in Sv per MBq / m^2) and, after a nuclear war, the degree of climatic perturbation that might be experienced. For this study, we consider two ages (adult and child), two sexes, the four significant nuclides (Sr-89, Sr-90, I-131, and Cs-137), six (potential) food types, one organ (the Total Body, wherein the doses from individual nuclides can be summed to give a meaningful total), and three degrees of climatic perturbation (that could be brought on by soot and smoke lofted into the atmosphere after a nuclear war). This sheet considers all 4 of the significant nuclides. The sheets that follow (E-1 to E-4) each apply to a specific nuclide.

1. Enter how many days *after the start of the war* that the foraged food was obtained, first consumed, and all gone.
   a. Day food was obtained (refer to Work Sheet item 9): ________
   b. Day food was first consumed: ________
   c. Day food was all gone (Work Sheet item 14e): ________

2. Using Tables 6 and 7 (or equations at bottom of tables),input item 1b as t_i and item 1c as t_f. Obtain decay factors for Sr-89 and I-131 and enter below and at item b on tables of E-1 and E-3.
   Decay factor for Sr-89: ________ Decay factor for I-131 ________

3. Energy units needed per day.
   a. On the Work Sheet, Item 7a, the minimum number of energy units per day that *all persons* in the refuge would require was entered. Enter that value below.
   Min. number of energy units: ________ kJ or kcal (cross out one)

   b. From item 7c of the Work Sheet, enter the energy units per day for the person for which dose estimates are being calculated.
   Person's daily energy units: ________ kJ or kcal (cross out one).

4. For the food type, enter the fraction by which the DCF would be changed by climatic perturbations. Table 2 may be used as a guide.
   Climatic perturb. factor for Milk: ______ Beef: ______ Poultry: ______
   Leafy veg.: ______ Non-leafy veg.: ______ Grain: ______

5. Fill in the table below (be sure that correct values for item d are selected; the values without parentheses are in *kg/day*, those within parentheses are in *pounds/day*):

		TYPE OF FOOD					
	ITEM	MILK	BEEF	POULTRY	LEAFY VEG.	NON-LEAFY VEG.	GRAIN
a.	Total kg (or lb.) of *each* foraged food (see Sheet D)						
b.	Work Sheet item 14d (Days foraged food lasts)						
c.	Kg.(or lb.) of food per day for person: a/b * 3b/3a						
d.	Ave. Daily U.S. Diet kg / day (lb. / day)	Child: 0.623 (0.233) Adult: 0.360 (0.163)	Child: 0.113 (0.060) Adult: 0.277 (0.126)	Child: 0.017 (0.008) Adult: 0.030 (0.014)	Child: 0.021 (0.010) Adult: 0.062 (0.028)	Child: 0.022 (0.010) Adult: 0.025 (0.011)	Child: 0.025 (0.011) Adult: 0.117 (0.053)
e.	Ratio: c / d kg / kg or (lb.) / (lb.)						

6. Go to Sheet E-1 for Sr-89.

Sheet E-1

Internal Dose from Ingestion of Foods with Sr-89

		TYPE OF FOOD					
	ITEM	MILK	BEEF	POULTRY	LEAFY VEG.	NON-LEAFY VEG.	GRAIN
a.	Ratio: c / d from Sheet E, item e						
b.	Decay Correction, from Sheet E, Item 2						
c.	Climate Pert. factor from Sheet E, Item 4						
d.	Product of Corrections (a x b x c)						
e.	DCF- Sv per MBq/sq m, from Table 1 of text						
f.	Corrected DCF (d x e)						
g.	Integ. Dep. - MBq . sq. m for location. See footnote.						
h.	Total Body Internal Dose (Sv) (f x g)						
Sum of doses for all food types= ________ Sv.							

*The integrated deposition is obtained by multiplying Work Sheet item 10a by 18. (the conversion value in Table 3 for Sr-89).

Go to Sheet E-2 for Sr-90.

Sheet E-2

Internal Dose from Ingestion of Foods with Sr-90

		TYPE OF FOOD					
	ITEM	MILK	BEEF	POULTRY	LEAFY VEG.	NON-LEAFY VEG.	GRAIN
a.	Ratio: c / d from Sheet E, item e						
b.	Decay Correction	1.0	1.0	1.0	1.0	1.0	1.0
c.	Climate Pert. factor, from Sheet E Item 4.						
d.	Product of Corrections (a x b x c)						
e.	DCF- Sv per MBq/sq m, from Table 1 of text						
f.	Corrected DCF (d x e)						
g.	Integ. Dep. - MBq . sq. m for location. See footnote.						
h.	Total Body Internal Dose (Sv) (f x g)						
Sum of doses for all food types= ________ Sv.							

*The integrated deposition is obtained by multiplying Work Sheet item 10a by 0.11 (the conversion value in Table 3 for Sr-90).

Go to Sheet E-3 for I-131.

Sheet E-3

Internal Dose from Ingestion of Foods with I-131

		TYPE OF FOOD					
	ITEM	MILK	BEEF	POULTRY	LEAFY VEG.	NON-LEAFY VEG.	GRAIN
a.	Ratio: c / d from Sheet E, item e						
b.	Decay Correction, from Sheet E, Item 2						
c.	Climate Pert. from Sheet E, Item 4						
d.	Product of Corrections (a x b x c)						
e.	DCF- Sv per MBq/sq m, from Table 1 of text						
f.	Corrected DCF (d x e)						
g.	Integ. Dep. - MBq . sq. m for location. See footnote.						
h.	Total Body Internal Dose (Sv) (f x g)						
Sum of doses for all food types= ________ Sv.							

*The integrated deposition is obtained by multiplying Work Sheet item 10a by 66. (the conversion value in Table 3 for I-131).

Go to Sheet E-4 for Cs-137.

Sheet E-4
Internal Dose from Ingestion of Foods with Cs-137

For Cs-137, enter integrated deposition (MBq/sq. m) where food was obtained

		TYPE OF FOOD					
	ITEM	MILK	BEEF	POULTRY	LEAFY VEG.	NON-LEAFY VEG.	GRAIN
a.	Ratio: c / d from Sheet E, item e						
b.	Decay Correction	1.0	1.0	1.0	1.0	1.0	1.0
c.	Climate Pert. from Sheet E, Item 4						
d.	Product of Corrections (a x b x c)						
e.	DCF- Sv per MBq/sq m, from Table 1 of text						
f.	Corrected DCF (d x e)						
g.	Integ. Dep. - MBq . sq. m for location. See footnote.						
h.	Total Body Internal Dose (Sv) (f x g)						
Sum of doses for all food types= ________ Sv.							

*The integrated deposition is obtained by multiplying Work Sheet item 10a by 0.12 (the conversion value in Table 3 for Cs-137).

Go to item 18 of the Internal Dose Work Sheet.